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16. ABSTRACT

This report compares the application and testing of the following five independent cathodic protection (CP) systems installed on three reinforced concrete bridge decks: 1) Coke Breeze; 2) Metallized Zinc; 3) Raychem "Ferex 100"; 4) Eltech "Elgard 210"; 5) Conductive Polymer.

All five CP systems were installed under a single contract and work was performed by the same contractor during the summer of 1988. Construction methods, materials, and the difficulties encountered in installing each type of system are included.

During the six year study period (November 1988 to November 1994), all five systems were monitored regularly. Parameters monitored were driving voltage, current density, and polarization decay. The efficiency of providing corrosion protection for each system based on these parameters is compared. All five CP systems met or exceeded the four hour polarization decay test criteria established by the National Association of Corrosion Engineers (NACE).

The Coke Breeze, the Metallized Zinc, and the Conductive Polymer were independently evaluated in 1992 by corrosion consultant for the Strategic Highway Research Program (SHRP). A second, independent SHRP contractor for the Strategic Highway Research Program (SHRP). A second, independent SHRP contractor evaluation of these systems (except the Conductive Polymer) was conducted in 1994. Both times, the contractors found the systems to be performing efficiently according to NACE criteria.

17. KEYWORDS
Reinforced Concrete, Corrosion, Cathodic Protection, Zinc Metallizing, Coke Breeze, Raychem "Ferex 100", Eltech "Elgard 210", Conductive Polymer, Bridge Deck Cathodic Protection, Impressed Current, Polarization Shift

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ENGINEERING SERVICE CENTER

OFFICE OF MATERIALS AND FOUNDATIONS

INSTALLATION AND OPERATIONAL COMPARISON OF FIVE BRIDGE DECK CATHODIC PROTECTION SYSTEMS

Final Report # FHWA/CA/SD-96/20

Caltrans Study # F87SD26

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17. Key Words	18. Distribution Statement
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Neither the State of California nor the United States Government endorse products of manufacturers. Trade of manufacturers' names appear herein only because they are considered essential to the object of this document.

ACKNOWLEDGMENTS

The installation of a CP system on a bridge deck is sufficiently complex to sometimes strain the minds and will of the designer, the Resident Engineer, and/or Contractor alike. The simultaneous installation of five different CP systems on three structures, as was done for this project, can only add to that complexity.

The authors wish to first thank the Caltrans District 02 Resident Engineer, Ken Hallis, and his Assistant Engineer, John Rohr, for their combined efforts to maintain direction of this project. Their steadfast attention to the installation accuracy of each CP system ensured that the data recovered would be complete.

Thanks also to the Division of Structures Electrical Section (Walt Jacobson and Wayne Morehead) for their assistance in the installation design and "start-up" testing.

Special recognition is due the District 02 Electrical Maintenance Unit (under the supervision of Earl Millard and Roy Arnett) who have taken the bi-monthly control box measurements since the CP systems were energized.

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TABLE OF CONTENTS

TABLE OF CONTENTS (cont'd.)

LIST OF FIGURES

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd)

LIST OF FIGURES (Cont'd.)

LIST OF FIGURES (Cont'd.)

LIST OF TABLES

LIST OF TABLES (Cont'd)

EXECUTIVE SUMMARY

This report discusses the installation, operation, and effectiveness over a six year period of the following five independent cathodic protections systems applied to three reinforced concrete bridge decks on Interstate 5, north of Redding, California: 1) Coke Breeze, 2) Metallized Zinc, 3) Raychem "Ferex 100", 4) Eltech "Elgard 210", and 5) Conductive Polymer.

System Descriptions

The **Coke Breeze CP System** consisted of surface-mounted cast iron primary anodes, a conductive (coke breeze, mineral aggregate and asphalt) distribution layer, and an AC overlay.

The **Metallized Zinc CP System** was an arc-sprayed distribution grid of stripes over brass primary anode pads with an AC overlay.

The **Raychem "Ferex 100" CP System** was a proprietary system composed of flexible anode cable (conductive polymer coated copper wire) attached to the deck to form a series of loops and a reinforced concrete (with epoxy-coated rebar) overlay.

The **Eltech "Elgard 210" CP System** was also a proprietary system consisting of titanium distributor bars, a titanium mesh distribution anode attached to the deck, and a reinforced concrete (with epoxy-coated rebar) overlay.

The **Conductive Polymer CP System** was a new Caltrans design which consisted of a steel bus bar connected to a steel primary anode mesh, attached to the deck, encapsulated in a conductive polymer (a mixture of granular coke breeze, fluidized coke breeze, mineral aggregate, and polymerized resin) overlay.

Field Installation

Based on the number of person days for installation, the CP systems are ranked in ascending order: Coke Breeze, Conductive Polymer, Metallized Zinc, Raychem "Ferex 100", and Eltech "Elgard 210".

The Coke Breeze CP System was the easiest system to install. Conventional AC equipment and procedures were used to place the conductive layer and AC overlay. The mix design was altered because the specified grade of coke breeze was not available. Even though it was a little bit more difficult to blend the conductive mix due to the limited capabilities of the batch plants, the modified mix was very workable and had an excellent electrical resistivity.

The Metallized Zinc CP System grid was a series of transverse and longitudinal stripes to allow clear bonding areas for the AC overlay. Machine screws were used to enhance the mechanical connection between the stripes and the brass primary anode pads. In some areas, the metallized zinc disbonded from the bridge deck and the brass anode pads, due to the smooth surfaces. The disbonding was detected by sounding and the areas were stripped, recleaned, and restriped with metallized zinc.

Two cables were placed out of alignment in Lane 2 for the Raychem "Ferex 100" CP System. The cables were sticking out form under the overlay into Lane 1. This did not cause a problem with placement because the cables were covered when the overlay was placed in Lane 1. The misaligned cables did not cause any problems with the operation of the CP system.

Additional plastic cleats were needed for the Eltech "Elgard 210" CP Systems to anchor the mesh to the deck to prevent the mesh from "riding up" and causing potential short circuits. Epoxy coated reinforcing steel was placed in the overlay for this system and the Raychem system to guard against premature failure due to heavy truck traffic.

Since there was a possibility for stray current corrosion between the overlay steel and the distribution anodes for the Raychem "Ferex 100" and Eltech "Elgard 210" CP Systems, independent CP systems were wired to protect the overlay steel for these systems using the installed Raychem and Eltech distribution anodes.

Since this was the first Conductive Polymer CP System of this type, the conductive polymer for the distribution anode was mixed on site in small batches. Because this was a new process, some improperly mixed batches resulted in the removal and repair of some portions of the conductive polymer overlay. Improper storage of the polyester resin resulted in discarding several drums. This resulted in delays when placing the overlay.

In addition, portions of the overlay are cracked and rust stains have appeared at the cracks due to the shallow placement of the steel mesh at these locations. The mesh started to corrode once it was exposed to the environment at the cracks.

Cathodic Protection Operation and Effectiveness

Throughout the six year study period, all the systems have operated effectively. Each system has achieved the required 100 mV minimum polarization decay. Initial driving voltage settings have remained the same, however, recorded voltages have varied due to the natural electrical resistance changes within the systems through this period.

Coke Breeze CP System

The coke breeze CP system has been operating effectively since installation. The system has continually met the four hour 100 mV minimum polarization decay. The asphalt overlay has continued to perform well under varied loading and weather conditions. Cracking in the asphalt overlay was minimal.

Metallized Zinc CP System

The high average polarization decay values for the metallized zinc CP system has not been completely understood. Inconsistent values were recorded at the same half-cell ports during different surveys. During the same survey, however, some of the ports exhibited excessive potentials probably due to electrolytic leakage, while other ports in the system exhibited more representative potentials. The driving voltage had not been changed.

Raychem "Ferex 100" CP System

The average current density for the Raychem "Ferex 100" CP system was slightly lower than the Coke Breeze, Metallized Zinc, and Eltech systems. This difference was reflected in the lower average four hour polarization decay values and higher average voltage of this system.

Eltech "Elgard 210" CP System

The average voltage for the Eltech "Elgard 210" CP system was the highest of all CP systems. The overlay CP system had the highest current density of all CP systems. Four hour polarization decays exceeded the 100 mV criteria.

Some corrosion of the overlay reinforcing steel was detected in the summer of 1997. The cause of this corrosion is being investigated.

Conductive Polymer CP System

With the exception of NE Quadrant, the average current density of the Conductive Polymer CP System was lower than those for the other four systems. Four hour polarization decays exceeded the 100 mV criteria. The lower current density for this system may be due, in part, to the impermeability of the polymer overlay which would reduce the migration of oxygen to the bridge deck concrete.

Recurring malfunctions of the rectifier for the NW Quadrant of the Conductive Polymer CP System resulted in lower average driving voltage and four hour polarization decay. This problem was corrected by connecting the NW Quadrant to the rectifier for the SW Quadrant.

An independent field evaluation of the Coke Breeze, Metallized Zinc, and the Conductive Polymer CP Systems was conducted in April 1992 by a corrosion consultant for the Strategic Highway Research Program (SHRP). A second evaluation of these systems (except the Conductive Polymer) was performed by another SHRP consultant in November 1994. Both consultants concluded that the systems were functioning effectively.

Life Expectancy

The life expectancies of the five deck CP systems were estimated based on calculations from the data recovered from this study, accelerated lab test results on some of these anode materials, and the information provided in the SHRP publication, "Cathodic Protection of Concrete Bridges: A Manual of Practice." Life expectancies are as follows:

-Coke Breeze CP System	20 years
-Metallized Zinc CP System	<20 years
-Raychem "Ferex 100" CP System	unknown*
-Eltech "Elgard 210" CP System	35 years
-Conductive Polymer CP System	>40 years

*Life expectancy is unknown due to reported problems with anode degradation and embrittlement, evidently due to local hot spots. This system is not widely used today.

Installation Costs

The contract cost (in 1988 dollars) per square meter to install each CP system was as follows:

-Coke Breeze CP System	\$202.90/m^2	(\$18.85/ft^2)
-Metallized Zinc CP System	\$270.60/m^2	(\$25.14/ft^2)
-Raychem "Ferex 100" CP System	\$202.90/m^2	(\$18.85/ft^2)
-Eltech "Elgard 210" CP System	\$225.50/m^2	(\$20.95/ft^2)
-Conductive Polymer CP System	\$192.03/m^2	(\$17.84/ft^2)

1.0 INTRODUCTION

Concrete normally provides excellent corrosion protection for embedded reinforcing steel. At some threshold of chloride concentration and given an adequate supply of oxygen and moisture, the embedded steel begins to corrode and damage to the concrete soon follows.

The Federal Highway Administration (FHWA) has been a strong advocate of cathodic protection (CP) as a reliable means of controlling corrosion in steel reinforced concrete bridge decks contaminated by salt. The first ever bridge deck cathodic protection system (coke breeze distribution anode) was developed by the California Department of Transportation (Caltrans) and installed on the Sly Park Bridge in 1973[1].

As a result of the success of this initial installation, Caltrans installed seven additional Coke Breeze CP systems on bridge decks in 1974 and 1975[2]. Caltrans initiated this second research project, which was also sponsored by the FHWA, to determine the effectiveness of cathodic protection on these structures and to test a variety of primary anodes, rectifiers, distribution anode thicknesses, and AC overlay thicknesses.

Three of the seven structures (Hampshire Rocks UC (Left), North Fork Feather River, and the Lake Almanor Spillway) were located in areas considered severe for icing and salting. The remaining four structures (Upper Salt Creek UC Left/Right and O'Brien UC Left/Right), although not in a severe icing and salting area, were included in the study to test a variety of light dead load CP anode concepts. In 1985, the original deck CP distribution overlays of three of the seven bridges were damaged during a routine roadway maintenance repair procedure. As a result, the Coke Breeze CP distribution anode on the structures at the O'Brien UC (Left) and the Upper Salt Creek UC (Left and Right) were subsequently removed.

Also in 1985, the first bridge deck CP system using metallized zinc was installed by Caltrans on the deck of the East Camino UC located on State Route 50, approximately 8 km (5 miles) east of Placerville, California[3].

By this same date, Caltrans, industry, and others had sufficiently developed the Coke Breeze and other types of bridge deck CP systems that it was felt a comparative study of state-of-the-art CP systems was warranted. The structures at O'Brien (Left) and Upper Salt Creek (Left and Right) were considered for this comparative study. As an added bonus, the rectifiers, controller cabinets and most of the wiring from the original CP systems applied to these structures were reused.

This report discusses the application of five cathodic protection systems applied to three bridge decks in 1988 and their initial monitored results over a 6 year period. The CP systems studied are as follows: Coke Breeze, Metallized Zinc, Raychem "Ferex 100", Eltech "Elgard 210", and a newly developed Caltrans Conductive Polymer Overlay. The effectiveness and efficiency of each of these impressed current CP systems are also discussed.

2.0 CONCLUSIONS

During the course of the research, comparisons have been made between five independent CP systems. These comparisons include: preliminary site results; field installations; and CP operation and effectiveness.

The following conclusions are based on the review and comparison of the operational results from the following five independent CP systems: 1) Coke Breeze, 2) Metallized Zinc, 3) Raychem "Ferex 100", 4) Eltech "Elgard 210", and 5) Conductive Polymer.

2.1 Preliminary Site Results

The three structures used in this study are not located in areas where severe icing and salting would be expected. This is supported by bridge deck corrosion potential surveys performed prior to installation of the CP systems.

More deck delamination repair was needed at the Upper Salt Creek UC (Left) structure in comparison to the remaining two structures (Upper Salt Creek UC, Right and O'Brien UC, Left). This was due to the shallow placement and subsequent corrosion of a significant area of the reinforcing steel; 15% less than 25 mm (1 in), at that structure.

2.2 Field Installation

A comparison between the five CP systems indicated that the ease of installation varied dramatically. The installation time ranking of the five CP systems based on the number of person-days needed to install each system are as follows with the shortest installation time indicated first:

Coke Breeze/Asphalt
Conductive Polymer
Metallized Zinc
Raychem "Ferex 100"
Eltech "Elgard 210"

The following is an outline of the variables of each CP system that influenced the installation time.

COKE BREEZE CP SYSTEM

Overall, this was the easiest system to install. Use of conventional AC placement equipment and procedures ensured construction crew familiarity.

The mix design for the distribution anode differed from that called for in the specifications. This change was necessary to increase the stability of the distribution anode because the prescribed gradation of coke breeze could not be obtained by the contractor.

There were difficulties in blending the new mix of coke breeze, mineral aggregate, and asphalt due to equipment limitations at the AC plants. The coke breeze and mineral aggregate were dry-mixed at one plant and transported to a separate plant where the asphalt was added after the mixture was reheated. Although inconvenient, this process worked well.

The modified coke breeze and mineral aggregate mix, was similar to that specified by the Ontario Ministry of Transportation[4]. The mix was very workable and provided excellent CP current delivery capability. Laboratory tests indicate the new mix had a stability value of 28 and an electrical resistivity less than 1 ohm-cm.

METALLIZED ZINC CP SYSTEM

The metallized zinc coating was applied as stripes onto the deck to allow for a clear bonding area for the AC overlay between each stripe.

Because there was some concern the metallized zinc stripe would disbond from the top surface of the primary anode brass pads (due to the extra thickness of zinc at these locations), additional mechanical connections were used. The zinc coating and brass pad were drilled and tapped and #10-32 machine screws were used to secure the zinc stripe to the brass pad. This procedure was successfully accomplished to provide long term electrical connection.

The method of using the stranded wires encapsulated in the zinc stripe to deliver current to the deck was tested against the use of brass anode pads to deliver current. Anomalous readings obtained during several polarization decay tests at various half-cell ports made the evaluation of this method difficult. At this time, it is uncertain if the method could be used to replace the brass anode pads.

The equipment for placing the metallized zinc stripes suffered continual breakdowns. This resulted in delays in installing this system.

The metallized zinc stripes disbonded in several locations during installation. The stripes were tested by sounding and listening for a dull thud. The disbonded areas were detected and repaired by stripping, cleaning, and restriping the areas before placement of the asphalt concrete overlay.

RAYCHEM "FEREX 100" CP SYSTEM

Two sections of the Raychem anode cable were out of place when the concrete overlay for lane 2 was poured. When the lane change was made to begin work on lane 1, it was discovered that the two sections were sticking out of the concrete in two areas within 4.9 m (16 ft) of each other. The cables were covered when the concrete overlay for lane 1 was placed. No problems resulted from the misalignment when the system was energized.

ELTECH "ELGARD 210" CP SYSTEM

Additional plastic cleat anchors were needed to anchor the mesh to the deck to prevent the mesh from "riding up" and causing potential short circuits if the mesh came in contact with any bare areas of the epoxy coated overlay reinforcing steel. This was accomplished without any problems.

A short circuit was detected during the placement of the concrete overlay in zone 2. An anchor bolt used to hold the concrete grade form in place was accidentally placed in contact with the deck reinforcing steel mat. During the placement of concrete, the anode mesh shifted and came in contact with the anchor bolt, resulting in a direct short between the rebar mat and the anode mesh. This was soon located and a small section of the anode mesh was cut out to clear the bolt. No other short circuits were found.

ELGARD AND RAYCHEM OVERLAY CP SYSTEM

Epoxy coated reinforcing steel was placed in the overlay concrete to guard against premature failure due to the heavy truck traffic on this major Interstate highway.

Separate CP systems using the Elgard and Raychem distribution anodes were constructed to protect the overlay reinforcing steel from stray current from the Elgard and Raychem Deck CP systems. Data indicates that the overlay reinforcing steel is being protected according the 4 hour depolarization requirements as recommended by the National Association of Corrosion Engineers (NACE)[5].

In 1997, it was discovered that there was some corrosion of the epoxy-coated reinforcing steel in the Elgard overlay section. The cause for this corrosion is unknown at this time, but is being investigated further.

CONDUCTIVE POLYMER CP SYSTEM

Since this was the first installation of its kind, the conductive polymer was mixed on-site in small batches using three 0.25 m^3 (9 ft^3) mixers. The distribution anode was composed of a mixture of granular coke breeze, fluidized coke breeze, mineral aggregate and a binder of polymerized resin. The result was a conductive overlay that had an electrical resistivity under 2 ohm-cm. Within the overlay, a 150 mm x 150 mm (6 in x 6 in) wire mesh was placed to reinforce the overlay and provide an additional path for current delivery.

Two problems arose during the placement of the conductive polymer overlay. The first problem was a result of inconsistent mixing by the contractor. Several times the contractor did not thoroughly mix the polyester resin and the initiator prior to adding the aggregate. During the mixing of one batch, initiator was not added to the conductive polymer. This inconsistent mixing resulted in a section of uncured conductive polymer. Approximately 6.5 m^2 (70 ft^2) of the conductive polymer overlay had to be removed and repaired. The contractor sawcut the section and removed the polymer and wire mesh contained in it. A new piece of wire mesh was placed and the section was backfilled with properly mixed conductive polymer. Based on this experience, a repair procedure for future installations was developed.

The second problem occurred at the end of the SW quadrant. The contractor discovered the polyester resin had started to harden due to improper storage. The result was resin could not be used and the last 2.75 m (9 ft) could not be completed. The contractor obtained new polyester resin and completed the quadrant two weeks later by first reinstalling the conductive prime coat and then placing the overlay.

Portions of the overlay are cracking and rust stains have appeared at the cracks on the surface of the conductive overlay. This problem was caused by stresses within the conductive overlay due in part to the shallow placement of the primary anode mesh wire grid. Corrosion of the wire grids progressed after the mesh wires were exposed to the environment through the cracks.

2.3 CP Operation and Effectiveness

Based on six years of monitoring, all five CP systems are operating successfully and have exceeded the 100 mV depolarization decay criteria over a four hour test period as recommended by NACE. All potential and current measurements were taken with accurate external digital instruments throughout this study. Analog meters, normally provided as part of the rectifier, were deemed too inaccurate for performing research testing.

Higher than normal polarization decay values were measured at some of the half-cell test ports for both the Metallized Zinc and the Conductive Polymer CP systems. It is suspected that some of the test ports developed leaks at the bridge deck surface. For the metallized zinc CP system, the problem occurred during monitoring when the wetting agent placed in some of the half-cell ports leaked under the seal and came into contact with the zinc stripe. For the conductive polymer CP system, the problem occurred when the wetting agent placed in some of the half-cell ports leaked under and came into contact with the wire mesh. The direct electrolytic contact between the distribution anode and the half-cell affected the accuracy of the collected data at these locations. This difficulty, however, did not compromise the operation of these systems.

The Raychem "Ferex 100" CP system was the least efficient (from polarization decay data) system of the five systems tested. Although not encountered on this project, the anode has had problems on other projects with degradation and embrittlement due to local corrosion hot spots. For these reasons, the Raychem "Ferex 100" CP system is not recommended for use.

The Conductive Polymer CP system required the least current density to achieve its depolarization decay criteria.

During the study, the rectifier for the northwest quadrant of the Conductive Polymer CP system malfunctioned resulting in lower than normal driving voltage and polarization decay values. This rectifier was removed and the NW quadrant was connected to the SW quadrant. The driving voltage of the rectifier for the SW quadrant was increased to maintain the same current density for both quadrants.

On two separate occasions, the operation and effectiveness of some of the CP systems installed for this study were independently verified by corrosion engineering consultants hired by the Strategic Highway Research Program (SHRP) as part of a program to monitor the long term performance of existing cathodic protection installations. The testing date, CP systems, and evaluations are as follows:

1992 - Metallized Zinc, Coke Breeze, and Conductive Polymer CP systems - Evaluation concluded that both CP systems were functioning properly.

1994 - Metallized Zinc and Coke Breeze CP systems - Evaluation concluded that both CP systems were functioning properly.

2.4 Life Expectancy

The life expectancies of the five deck CP systems were estimated based on calculations from the data recovered from this study, accelerated lab test results on some of these anode materials, and the information provided in the SHRP publication, "Cathodic Protection of Concrete Bridges: A Manual of Practice."

Caution should be used with these estimations because anode consumption, while a major component of the evaluation, is not the only cause for system failure. Other types of failure can include breakdown of the conductive materials within the distribution anode, disbondment from the deck, and isolation between conductive components within the distribution system.

Life expectancies of the five deck CP systems evaluated in the study are estimated (from SHRP reports) as follows:

-Coke Breeze CP System	20 years
-Metallized Zinc CP System	<20 years
-Raychem "Ferex 100" CP System	unknown*
-Eltech "Elgard 210" CP System	35 years
-Conductive Polymer CP System	>40 years

*Life expectancy is unknown due to reported problems with anode degradation and embrittlement, evidently due to local hot spots. This system is not widely used today.

2.5 Installation Costs

The costs associated with installing the CP systems for this study pertain to the actual contracted installation costs including contract change orders (CCO's) made during the construction period. Testing and personnel costs for gathering research data have not been included.

The contract cost per square meter (square foot) to install each CP system was as follows:

-Coke Breeze CP System	$202.90/m^2$	($18.85/ft^2$)
-Metallized Zinc CP System	$270.60/m^2$	($25.14/ft^2$)
-Raychem "Ferex 100" CP System	$202.90/m^2$	($18.85/ft^2$)
-Eltech "Elgard 210" CP System	$225.50/m^2$	($20.95/ft^2$)
-Conductive Polymer CP System	$192.03/m^2$	($17.84/ft^2$)

3.0 RECOMMENDATIONS

Based on the findings of this research, the following recommendations are made:

1. The coke breeze/asphalt mix design used for this project should be used for future Coke Breeze CP installations.

2. Due to the high asphalt binder content that is required for the coke breeze/asphalt CP mix, contractors should be alerted that their existing AC plants may need to be modified. Conventional asphalt concrete seldom exceeds 10% asphalt content and most mix plants will be preset to that maximum. The coke breeze/asphalt CP mix requires approximately 13% binder.

3. Future installations of the conductive polymer CP system should not include the wire mesh reinforcement in the overlay. The mix is sufficiently conductive to deliver the required current.

4. The Raychem "Ferex 100" CP system should not be used for future installations due to its low efficiency and possible early anode degradation and embrittlement.

5. To reduce the chance of inaccurate values, future polarization surveys should be conducted using a moist sponge attached to the end of the reference cell as the contact between the reference cell and the concrete surface instead of filling the half-cell ports with water.

6. A remote monitoring system should be installed at control boxes to monitor each CP system through a telephone modem.

7. Systems that are recommended for future sites are the Eltech "Elgard 210", Coke Breeze, and Conductive Polymer CP Systems.

8. Results of this study should be used for developing corrosion criteria and guidelines for use as a maintenance strategy.

4.0 IMPLEMENTATION

Copies of this report will be sent to Caltrans district and headquarters offices and to the Federal Highway Administration.

Information gathered from this study will be used to develop a program for the use of cathodic protection on steel reinforced concrete bridge decks subject to corrosion in California. Two examples of programs presently being developed are as follows:

1. The Caltrans Office of METS, Corrosion Technology Section is presently working with the Division of Structures (DOS) to develop a series of CP Guidelines which will be incorporated in the DOS structure maintenance program. These guidelines will allow a designer to progress through the various stages of maintenance and implement the maintenance program needed.

2. An information system is presently being developed within the Caltrans METS, Corrosion Technology Section that will include a design and installation outline of each state-of-the-art CP system. The results of this study will be used to develop this program.

The Caltrans Office of METS, Corrosion Technology Section will assist the districts or headquarters personnel in the design and installation of CP systems using the technologies reported in this study.

5.0 CATHODIC PROTECTION INSTALLATIONS

5.1 Test Sites and CP System Descriptions

The three structures included in this study are the Upper Salt Creek Undercrossing (Left, bridge number 6-159L), Upper Salt Creek Undercrossing (Right, bridge number 6-159R), and O'Brien Undercrossing (Left, bridge number 6-148L).

These structures are located on Interstate 5, approximately 29 km (18 miles) north of the city of Redding, California. The Upper Salt Creek structures are at elevation 344 m (1130 feet) while the O'Brien UC is at elevation 411 m (1350 feet), (Figure 5.1-A). Site parameters for these structures are shown in Table 5.1-A.

Table 5.1-A

Bridge Site Parameters

	UPPER SALT CREEK UC (RIGHT) Br# 6-159R	UPPER SALT CREEK UC (LEFT) Br# 6-159L	O'BRIEN UC (LEFT) Br# 6-148L
LOCATION *	02-Sha-5-R37.1	02-Sha-5-R37.1	02-Sha-5-R32.0
STRUCTURE	Reinf. Conc.	Reinf. Conc.	Reinf. Conc.
TYPE	T-Beam	T-Beam	T-Beam
TRAFFIC	2 Lanes, Northbound	2 Lanes, Southbound	2 Lanes, Southbound
LENGTH	37.57 m (123.25 ft)	37.51 m (123.08 ft)	36.48 m (119.67 ft)
WIDTH	11.9 m (39 ft)	11.9 m (39 ft)	11.9 m (39 ft)
AREA	447 m^2 (4807 ft^2)	446 m^2 (4800 ft^2)	434 m^2 (4667 ft^2)
CURVE RADIUS	347 m (1138 ft), Right	362 m (1188 ft), Right	259 m (850 ft), Right
SKEW	16 Degrees	16 Degrees	20 degrees
X-SLOPE	-9%	-9%	11%
YEAR BUILT	1966	1966	1968

* DISTRICT - COUNTY - ROUTE - POST MILE

The average annual precipitation in the vicinity of the structures is approximately 1448 mm (57 inches). This is reported by the National Oceanic and Atmospheric Administration (NOAA) at the Shasta Dam Station, located approximately 16 km (10 miles) south of the structures.

Five different CP systems were installed on the decks of these three structures. All five were impressed current CP systems which deliver CP current through different distribution mediums as described in the following paragraphs and in Figure 5.1-B.

COKE BREEZE CP SYSTEM: This system was installed on the northern half of the Upper Salt Creek UC (Left) bridge deck. It was designed by Caltrans to deliver CP current to the deck reinforcing steel from an electrically conductive coke breeze/mineral aggregate/asphalt binder layer applied to the bridge deck surface at a thickness of approximately 48.3 mm (1.9 in) thick.

This conductive layer was covered with 57.15 mm (2.25 in) of asphalt concrete (AC) to protect the conductive distribution anode from traffic wear.

METALLIZED ZINC CP SYSTEM: This system was installed on the southern half of the Upper Salt Creek UC (Left) bridge deck. It was designed by Caltrans to deliver CP current to the deck reinforcing steel from a gridwork of metallized zinc applied to the bridge deck surface in 152 mm (6 in) wide stripes, spaced 0.3 m (1 ft) on center. The stripes were approximately 0.610 mm (0.024 in) thick. This system was also covered with an overlay to protect it from traffic wear.

RAYCHEM "FEREX 100" CP SYSTEM: This system was installed on the northern half of the Upper Salt Creek UC (Right) bridge deck. It is a proprietary system designed to deliver CP current to the deck reinforcing steel from a multi-strand mesh made up of flexible polymer coated metallic anode cables attached to the bridge deck surface. This system was covered with an epoxy coated steel reinforced Portland Cement Concrete (PCC) overlay to provide a distribution path for the CP current and to protect it from traffic wear.

ELTECH "ELGARD 210" CP SYSTEM: This system was installed on the southern half of the Upper Salt Creek UC (Right) bridge deck. It is a proprietary system designed to deliver CP current to the deck reinforcing steel from an oxide coated titanium mesh mat attached to the bridge deck surface. This system was also covered with an epoxy coated steel reinforced PCC overlay to provide a distribution path for the CP current and to protect it from traffic wear.

A separate cathodic protection circuit and rectifier wired to the same distribution anode as the deck CP system delivered CP current to the reinforcing steel within the concrete overlay for the Raychem "Ferex 100" and the Eltech "Elgard 210" CP systems. Since the reinforcing steel in the concrete overlay was epoxy coated, only damaged areas of the epoxy coating exists would receive cathodic protection.

CONDUCTIVE POLYMER OVERLAY CP SYSTEM: This system was installed on the entire surface of the O'Brien UC (Left) bridge deck. It is a designed by Caltrans to deliver CP current to the deck reinforcing steel from an electrically conductive polymer overlay applied to the bridge deck surface. The overlay consisted of coke breeze aggregate, mineral aggregate, and polymer resin binder. The overlay was approximately 43.2 mm (1.7 in) thick. Since this system was designed to serve as both the electrically conductive anode and as the traffic wear surface, no additional overlay was needed. To reinforce the overlay, a 150 mm x 150 mm (6 in x 6 in) steel wire mesh was placed in the overlay. The wire mesh also served as a redundant current path for CP.

Each of the Upper Salt Creek UC (Left and Right) bridge decks was divided into four distribution anode zones. Construction was performed in stages, one lane at a time, to minimize disruption to traffic flow in the open lane. For this report, each anode zone is identified by the corresponding traffic lane number where it is located (e.g., Metallized Zinc, Zone 1 = Lane 1 Quadrant), Figure 5.1-B.

The O'Brien UC (Left), located approximately 8 km (5 mi) south of the Upper Salt Creek structures, was also divided into four zones. All four zones were dedicated to the conductive polymer CP system. For ease of identification, the CP zones on this structure are identified by their location on the deck (e.g., NW Quadrant = Northwest Quadrant, etc.), Figure 5.1-B.

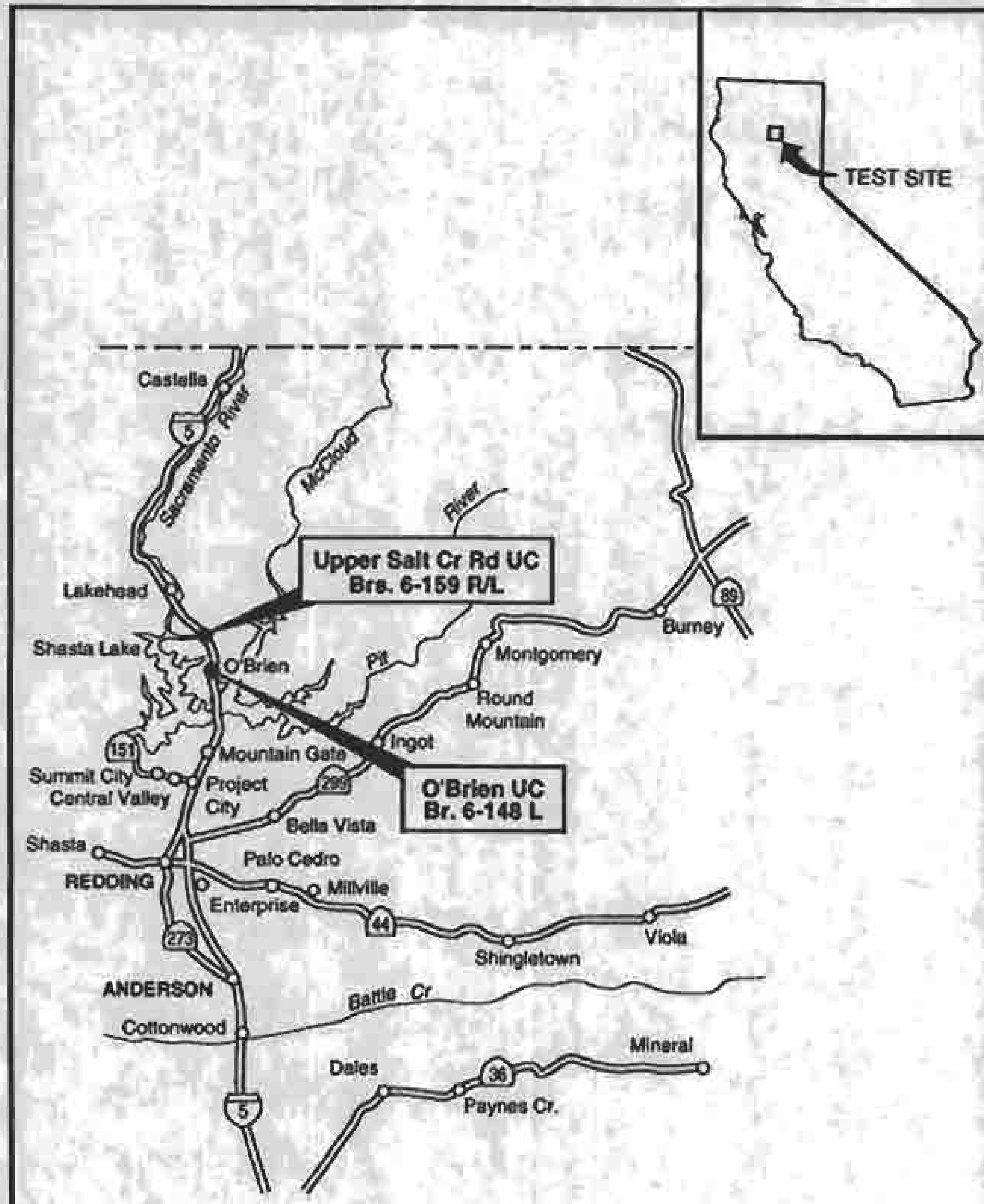


FIGURE 5.1-A Location Map for Upper Salt Creek UC and O'Brien UC

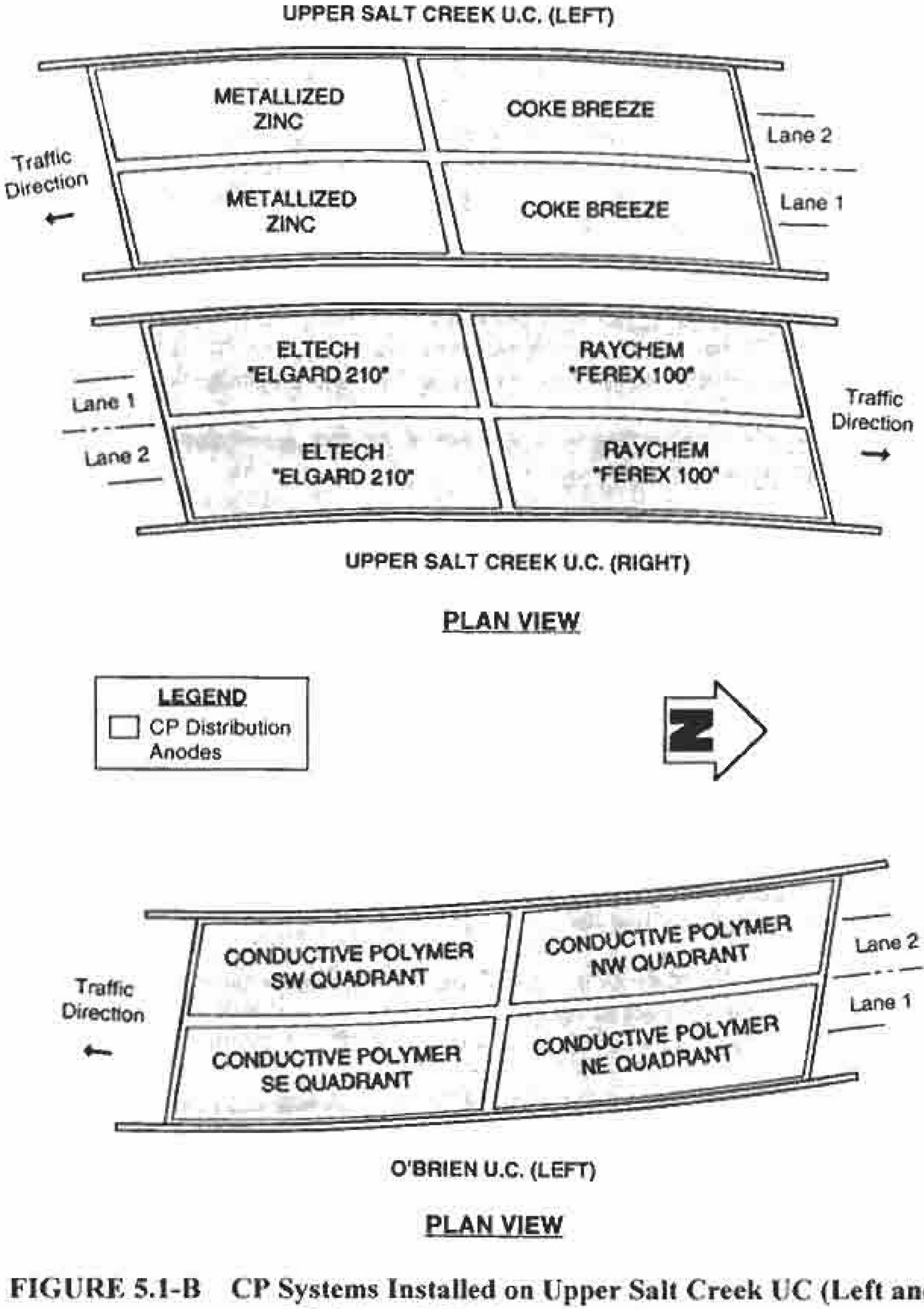


FIGURE 5.1-B CP Systems Installed on Upper Salt Creek UC (Left and Right) and O'Brien UC (Left)

5.2 Preliminary Site Repairs and Testing

Occasionally, deicing salts are applied to these bridge decks during the winter season to control ice formation. As a consequence, these structures have had a history of some corrosion damage which required patching to repair spalled and delaminated concrete.

While the average chloride concentration levels of these concrete decks were not extremely high, the following percentages of delaminated deck areas were patched prior to installing the CP systems: 14.5%, (Upper Salt Creek UC, Left); 4.7%, (Upper Salt Creek UC, Right); and 3.5%, (O'Brien UC, Left).

The decks were ground with a roto-mill to remove the existing AC overlay. Any AC residue remaining after roto-milling was sandblasted from the deck prior to repair of the spalled areas. An additional 6.35 mm (1/4 in) of concrete surface was also ground off the Upper Salt Creek UC (Right) deck in preparation for the concrete overlay that would be placed on that structure.

The following condition surveys were also part of the deck preparation. The results of these surveys are presented in Section 7.1.

DECK DELAMINATION AND PATCHING: Each bridge deck was surveyed to determine the existence of existing delaminated areas. Areas of spalled or delaminated concrete were repaired prior to placing the CP distribution anode.

The chain drag method was used to detect delaminated areas. Damaged concrete was removed with 6.8 and 13.6 kg (15 and 30 pound) pneumatic hammers. The exposed reinforcing steel and surrounding concrete surface areas were sandblasted and patched using a 9.5 mm (3/8 in) maximum pea gravel/7-sack Portland Cement concrete mix.

CHLORIDE CONCENTRATION: Two inch diameter cores were taken from the concrete deck of each bridge. The recovered cores were analyzed to determine chloride concentration of the deck concrete. Each core was cut into 25 mm (1 in) segments relative to depth of the concrete deck. The segments were individually crushed and total chloride content was determined in accordance with California Test 404[6].

CONCRETE COVER SURVEYS: No concrete cover surveys were conducted immediately prior to placing the CP systems on these structures. This data had previously been gathered during the initial CP installation at these structures in 1975[3].

HALF-CELL CORROSION POTENTIAL SURVEYS: A half-cell corrosion potential survey was conducted on each deck surface in accordance with ASTM Designation C-876[7]. The surveys on Upper Salt Creek UC (Left), and O'Brien UC (Left) were conducted during the summer of 1987, while the survey of Upper Salt Creek (Right) was conducted during the summer of 1988. Figure 5.2-A shows the measuring technique used during these surveys and the typical placement of saturated sponges at each intersecting point of the 1.2 m (4 ft) grid pattern.

SHORT CIRCUIT TESTS: Tests to detect the possible presence of electrical short circuits in the bridge deck were also conducted.

As with any CP system, there should not be any unintended metallic paths between the distribution anode and the reinforcing steel being protected (e.g., exposed tie wires, form nails touching the reinforcing steel, etc.). Otherwise, an electric short circuit will occur between the distribution anode and the deck reinforcing steel.

An electrical short circuit detector, developed by Caltrans, was used to find short circuits in the deck. Since electrical shorts could appear in the form of small tie wires, an testing apparatus was needed to cover a large area and still detect the metal. The apparatus developed was a sponge roller that was rolled across the deck, similar to a lawn mower and provided the electrical contact between any exposed metal and the test circuit. A power supply operating at 30 V and 0.5 A was connected between the roller and the reinforcing steel. A voltmeter also connected between the reinforcing steel and the roller provided a visual indication of a short circuit. Once the sponges on the roller, wetted with saltwater, came into contact with metal attached to the reinforcing steel, the voltmeter dropped to near zero volts. Otherwise, an open circuit voltage of 30 V was indicated on the voltmeter. A schematic and photograph of its operation are shown in Figures 5.2-B and 5.2-C.

FIGURE 5.2-A Corrosion Potential Survey, Upper Salt Creek UC (Right)

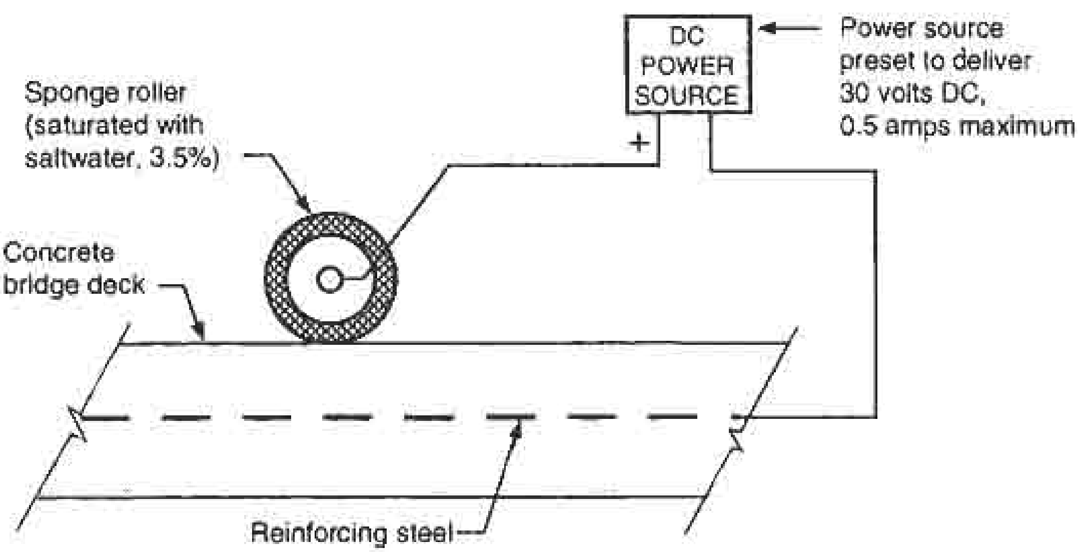


FIGURE 5.2-B Schematic of Deck Short Circuit Test

FIGURE 5.2-C Deck Short Circuit Test

5.3 COKE BREEZE CP SYSTEM

A. General Operation

The Coke Breeze CP system was installed on the northern half of the Upper Salt Creek UC (Left) bridge deck. The total surface area of the distribution anode was 210.1 m^2 (2261.3 ft^2). This impressed current system delivers CP current from the rectifier through cast iron primary anodes epoxied to the bridge deck. From these pads, the current is transferred to an electrically conductive layer composed of coke breeze, mineral aggregate, and asphalt which distributes CP current across the surface of the concrete and through the deck to the reinforcing steel. This system is then covered with an asphalt concrete (AC) overlay to protect the conductive layer from traffic wear.

B. Installation

The Coke Breeze CP system consisted of two independently constructed zones on the bridge deck, separated by a 0.6 meter (2 foot) nonconductive area, where no coke breeze layer was placed: Lane 2 and the outside shoulder, and lane 1 and the inside shoulder (Figure 5.3-A). The two zones of this CP system, although independently constructed, were later connected together through the wiring system to a common CP rectifier. To ensure separation from an adjacent CP system and to guard against the possibility of short circuits developing at the expansion joints of the structure, nonconductive AC areas were used.

The initial design called for a 0.6 m (2 foot) nonconductive area between each coke breeze zone and the adjacent two zones of the Metallized Zinc CP system. While this was accomplished during the installation of zone 1, the nonconductive area was increased to 0.9 m (3 ft) to accommodate the absence of one of the transverse stripes of the adjacent metallized zinc distribution anode.

After the deck was prepared and sandblasted, the Coke Breeze CP system was installed in three stages: (1) the cast iron anodes were placed; (2) the coke breeze/asphalt layer was applied; and (3) an AC overlay wearing surface was paved.

CAST IRON PRIMARY ANODES: Eight "Type II Durichlor-51" bridge deck anode pads were used as the primary anodes for the Coke Breeze CP system. The elliptically-shaped pads were made of high-silicon, cast iron and were 229 mm (9 in) long, 152 mm (6 in) wide, and 28.6 mm (1-1/8 in) thick (Figure 5.3-B). Four anodes, spaced along the shoulder of the two independent zones, were epoxied to the deck with the bottom surface of the anode flush with the top surface of the bridge deck (Figure 5.3-C).

Before epoxying the cast iron anodes to the deck, the area of concrete under the anode was removed to a depth of 12.7 mm (1/2 in). This recessed area was filled with epoxy (Concresive AEX-1419). The epoxy layer bonded the anodes in place and electrically insulated the bottom surfaces of the anode so that CP current would be distributed to the coke breeze distribution anode rather than being allowed to go directly from the anode down to the reinforcing steel.

The electrical cables for each anode (8/7 gage stranded HMWPE insulated cable) were longitudinally laid out together along the deck and were placed through a cored hole in the deck so they could be wired to the rectifiers which were located under the structure. These cables were anchored to the concrete deck with plastic clips so that they remained intact and would not be damaged by the paving equipment that would be used later to place the coke breeze distribution anode.

COKE BREEZE/ASPHALT LAYER: Before the coke breeze distribution anode was placed, an asphalt emulsion (Type RS-1) tack-coat was applied to the surface of the bridge deck. By visual inspection, it was estimated that the application rate for the zone in lane #2 was approximately 0.23 L/m^2 (0.05 gal/yd^2), while that on the lane #1 zone was inadvertently heavier, between 0.45 to 0.68 L/m^2 (0.10 to 0.15 gal/yd^2). The tack-coat was also applied to the exposed surfaces of the cast iron anodes.

Coarse and fine mineral aggregates were added to the original coke breeze mix since the only available coke breeze (calcined bituminous, Asbury #99) was predominately single graded. This was done to produce a more stable mix design that could withstand heavy traffic loading. Laboratory stability tests, in accordance with California Test 366[8], and electrical resistivity tests, in accordance with Ontario Canada Test LS-286[9], were conducted to verify this mix design. Laboratory results produced samples with a Stability Value of 28 and resistivity value less than 1 ohm-cm.

The gradation of the coke breeze and mineral aggregates used for the conductive overlay mix are presented in Table 5.3-A:

Table 5.3-A

Gradation of Distribution Anode Mix

GRADING	COKE BREEZE (% PASSING)	MINERAL AGGREGATE* (% PASSING)	
		9.5 mm x #8 Size	#8 x #200 Size
12.5	--	100	--
9.5	100	93	--
#4	99	26	100
#8	77	3	76
#16	31	2	47
#30	7	1	31
#50	1	--	21
#100	--	--	15
#200	--	--	11

*Mineral aggregate was added to the original mix because of gradation of the coke breeze. This modified mix was placed on the bridge decks.

Due to the differences in density between the coke breeze and the added mineral aggregate two mixing plants were used to mix the coke breeze material. First, a cold feeder from a drum plant was used to dry-blend and sort the materials. Because this plant could not supply the 13% asphalt needed for the coke breeze mix, the dry-mixed material was transported to another batch plant where the blended mix was dried, fed into the batch bin, and combined with asphalt oil. The coke breeze was mixed at a temperature of approximately 110°C (230°F). The components of the mix are shown in Table 5.3-B:

Table 5.3-B

Conductive Distribution Anode Mix
Coke Breeze CP System

COMPONENT	PERCENT BY WEIGHT*
COARSE AGGREGATE (9.5 mm x #8 Size)	10 TO 11
FINE AGGREGATE (#8 x #200 Size)	42 TO 43
COKE BREEZE (Calcined, Asbury #99)	46 TO 47
ASPHALT BINDER (AR 4000)	13

*Changed from the original specifications

A standard AC paver (Blaw Knox PF-180) was used to place the coke breeze mix on the deck (Figure 5.3-D). Table 5.3-C presents the applied thicknesses and temperatures for the coke breeze layer.

Table 5.3-C

Coke Breeze Application

LANE NUMBER	THICKNESS Meters (Feet)	TEMPERATURE °C (°F)
1	Uncompacted, 0.049 to 0.058 (0.16 to 0.19)	110 (230)
1	Compacted, 0.036 to 0.039 (0.12 to 0.13)	66 (150)
2	Uncompacted, 0.052 to 0.061 (0.17 to 0.20)	107 (225)
2	Compacted, 0.036 to 0.043 (0.12 to 0.14)	71 (160)

Both lanes were initially compacted with two full passes by a 3626 kg (4 ton) roller and two final passes with a 10879 kg (12 ton) roller. To keep the edges of the coke breeze anode layer from breaking down as the rollers traveled off the coke breeze during the compaction runs, a temporary wooden form, the approximate thickness of the coke breeze layer, was placed along the ends of the panel (Figure 5.3-E). On completion of the compaction procedure, the coke breeze looked dense and well laid out.

Any coke breeze residue dropped in the clear areas between the zones was carefully cleaned up to eliminate the possibility of any electrical contact between the independent zones.

The 0.6 m (2 ft) non-conductive clear area separating the two independent zones was filled by hand with the AC overlay mix and compacted with a vibratory plate compactor to bring all surface areas up to the same grade as the coke breeze layer.

AC OVERLAY: After the coke breeze was compacted, and the paver was cleaned of any coke breeze residue, an AC overlay containing reinforcing polyfibers (BoniFibers) was placed over the top of the coke breeze. The 6.35 mm (1/4 in) long polyester reinforcing fibers, approximately 0.025 mm (0.001 in) in diameter, were blended in with the AC mix to provide structural strength. The same equipment used to install the coke breeze anode layer was used to place and compact the AC overlay. The AC overlay was compacted to approximately the same thickness and temperature for both lanes as shown in Table 5.3-D.

Table 5.3-D

AC Overlay Application

LANE NUMBERS	THICKNESS Meters (Feet)	TEMPERATURE °C (°F)
1 and 2	Uncompacted, 0.061 to 0.067 (0.20 to 0.22)	129 (265)
1 and 2	Compacted, 0.055 to 0.061 (0.18 to 0.20)	77 (170)

Specifications for the asphalt concrete and polyester reinforcing fiber are described in Appendix 10.6.

C. Installation Testing

With the exception of compaction and thickness tests, no additional tests were conducted during the installation of the coke breeze and AC overlay.

D. Summary of System Components

Table 5.3-E presents a summary of the basic components of the Coke Breeze CP system.

Table 5.3-E

Coke Breeze CP System Components
Upper Salt Creek UC (Left)

COMPONENT	DESCRIPTION	INSTALLATION
CP System	2 independent zones separated by 0.6 m (2 ft) wide clear area; Total anode area = 210.1 m^2 (2261.3 ft^2).	Installed: Summer 1988 Energized: November 1988
Primary Anodes	8 high silicon cast iron bridge deck anodes (Type II, Durichlor-51); 229 mm x152 mm x 28.6 mm (9 in x 6 in x 1-1/8 in) thick.	Epoxied to the bridge deck with 12.7 mm (1/2 in) thick recessed layer of Concresive AEX-1419 epoxy. Cables laid along deck through holes in deck to junction box below deck. Four anodes placed zone.
Tack Coat	Asphalt Emulsion (Type RS-1)	Lane 2 - approx. 0.23 L/m^2 (0.05 gal/yd^2); Lane 1 - approx. 0.45 to 0.68 L/m^2 (0.10 to 0.15 gal/yd^2)
Distribution Anode	38.1 mm (1-1/2 in) thick layer of graded coke breeze/AC conductive mix; resistivity 0.93 ohm-cm.	Placed with conventional paver, compacted by two passes with 3626 kg (4 ton) roller, and finished with two passes with 10879 kg (12 ton) roller.
AC Overlay	57.15 mm (2-1/4 in) thick asphalt concrete layer with polyester reinforcing fibers (Bonifibers).	Placed with same paving equipment as distribution anode.
Rectifier	Constant voltage. 20 volt DC, 5 ampere maximum capacity.	System rewired to existing rectifier.
Rebar Ground	Two independent #8 gauge wire leads.	CADWELDED to rebar mat at two places on opposite ends of structure rebar mat.

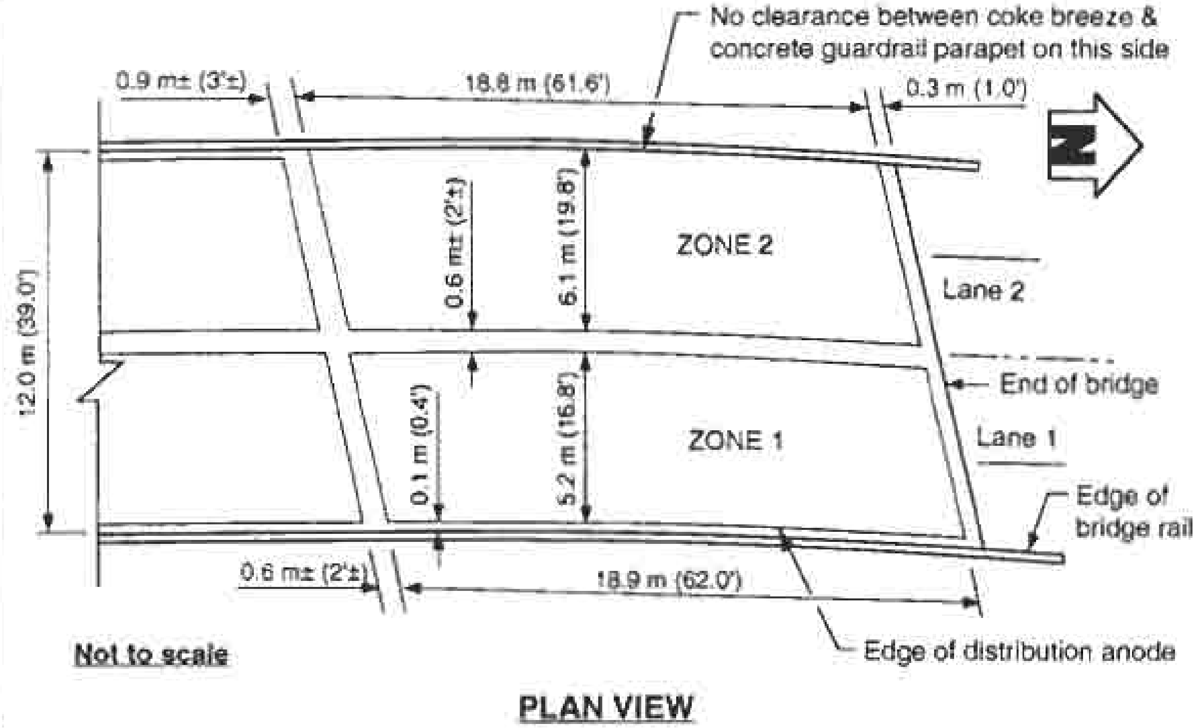


FIGURE 5.3-A Location and Dimensions of Distribution Anodes for Coke Breeze CP System (Zones 1 & 2), Upper Salt Creek UC (Left)

FIGURE 5.3-B Cast Iron Primary Anode Epoxied to Deck, Coke Breeze CP System, Upper Salt Creek UC (Left)

FIGURE 5.3-C Cast Iron Primary Anodes in Place, Coke Breeze CP System, Upper Salt Creek UC (Left)

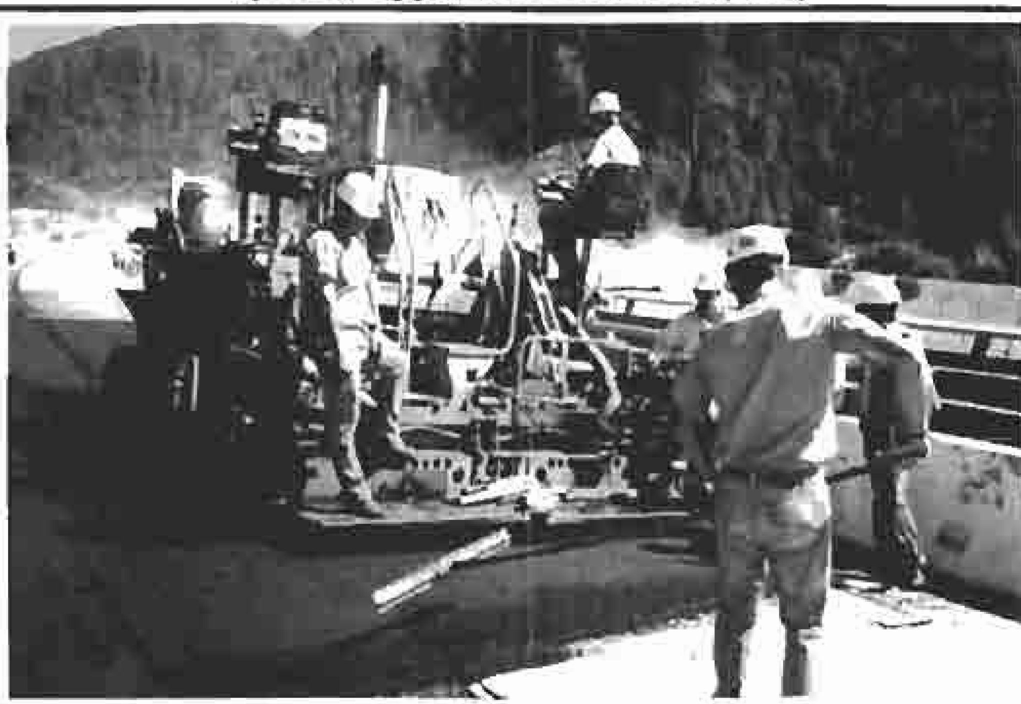


FIGURE 5.3-D Placing Coke Breeze Distribution Anode, Upper Salt Creek UC (Left)

FIGURE 5.3-E Compaction of Coke Breeze Distribution Anode, Upper Salt Creek UC (Left)

5.4 METALLIZED ZINC CP SYSTEM

A. General Operation

The Metallized Zinc CP system was installed on the southern half of the Upper Salt Creek UC (Left) bridge deck using the arc-spray metallizing process. The total surface area of the distribution anode was 191.6 m^2 (2062.1ft ^{2}). This impressed current system delivers CP current from the rectifier through brass anode pads epoxied flush to the concrete bridge deck. From these pads, the current is transferred to an electrically conductive metallized zinc coating (a grid system of stripes) which delivers CP current across and through the concrete deck to the reinforcing steel. The system is then covered with an AC overlay to protect the metallized zinc coating from traffic wear.

B. Installation

Separated by a 0.6 m (2 ft) non-conductive area, the Metallized Zinc CP system consisted of two independently constructed zones on the bridge deck: Lane 2 and the outside shoulder, and lane 1 and the inside shoulder (Figure 5.4-A). The two zones of this CP system were later connected together through the wiring system to a common rectifier. In order to ensure separation from an adjacent CP system and to prevent the possibility of short circuits from developing at the expansion joints of the structure, clear, non-conductive areas were also placed at these locations.

As explained in Section 5.3, the designed 0.6 m (2 ft) clear area between the metallized zinc anode and zone 2 the coke breeze anode, was increased to 0.9 m (3 ft).

Following sandblasting of the deck, the Metallized Zinc CP system was installed in four stages: (1) the primary anode pads were epoxied flush with the deck surface; (2) the transverse zinc stripes were sprayed; (3) the longitudinal stripes were sprayed; and (4) an AC overlay wearing surface was paved.

BRASS PRIMARY ANODE PADS: As presented in Figure 5.4-B, eight primary anodes, each 50 mm x 50 mm x 9.5 mm thick (2 in x 2 in x 3/8 in thick), were epoxied into holes flush with the deck. Epoxy (Concresive AEX-1419) was used to electrically insulate the top surface of the pads from the concrete deck surface. Wires (#6 gauge) from each pad were extended through 25.4 mm (1 in) diameter holes cored in the deck. These wires were, in turn, spliced to #12 gauge wire that went to the rectifier which was located beneath the structure.

Four pads were installed along the shoulder adjacent to lane 2, while three pads were installed similarly along the shoulder of lane 1. Figure 5.4-C shows a typical brass pad installation prior to metallizing the deck. In place of a fourth brass pad anode in lane 1, a #8 HWMPE insulated wire lead was epoxied in the cored hole to protrude 2 inches above the deck surface. The insulation was removed from the portion of the wire above the deck and the stranded wires were spread apart and encapsulated in the zinc stripe during the metallizing process (Figure 5.4-D). This technique was tried to determine if the wire method should be used in future installations instead of the brass primary anode pads.

There had been repeated concerns, by the designers, that the contact between the zinc stripe and the brass primary anode pad was solely from surface contact. While no failures, attributed to separation, had been noted to date, it was felt that an alternate contact method should be planned for future installations, if warranted.

Since the metallized zinc coating adheres to the deck by a mechanical bond, the deck was sandblasted before the coating was applied to clean and roughen both the concrete surface and the surface of the brass primary anode pads.

METALLIZING THE DECK: An "Eagle Arc E-600" portable arc spray metallizing gun was used to apply the zinc to the concrete surface. Table 5.4-A identifies the auxiliary equipment used along with the metallizing gun. This table also presents the metallizing parameters selected for the design of the CP system and those actually achieved during the metallizing process.

Precautions were taken to protect workers and the environment during the metallizing operation. The person spraying the metallized zinc was protected by an air fed respirator while the helpers and others in the vicinity wore particulate filter masks. Before the zinc was applied, however, a plastic enclosure was constructed around the metallizing operation to protect oncoming traffic from being exposed to the arc gun flash and to the zinc fumes. This three sided enclosure was 3.7 m wide, 2.4 m long, and 2.4 m high (12 ft wide, 8 ft long, and 8 ft high).

The metallizing gun was hand-held and each stripe was applied by spraying within a portable wooden template. The template sides were 6.1 m (20 ft) long, separated by a 152 mm (6 in) wide clear space to accommodate the width of the zinc stripes along shoulder of each being applied.

The equipment for placing the metallized zinc stripes suffered continual breakdowns. At two separate times, the generator for the metallizer and the metallizer itself malfunctioned. This resulted in delays in installing this system.

To apply the zinc stripes, the wooden template was positioned across the width of the zone being metallized. The template was moved in increments of 0.3 m (1 ft) after each stripe was completed. In this manner, 113 transverse zinc stripes (57 stripes in zone 1 and 56 stripes in zone 2) were applied at 0.3 m (1 ft) centers. Each stripe was 152 mm (6 in) wide and 5.56 m (18.25 ft) long, the full width of each zone. Guided by hand, the zinc was sprayed within the template at an average of 16 passes per stripe with the metallizing gun traversing across the deck interlocking zinc stripes (Figure 5.4-E). The zinc stripes also traversed each exposed brass primary anode pad previously placed flush with the deck surface.

Table 5.4-A

Arc Metallizing Parameters

SUBJECT	ORIGINAL DESIGN	AS PERFORMED
Metallizing Equipment: Metallizing Gun: Eagle Arc E-600 with two 13.6 kg (30 lb) wire reels. AC Generator: Cummins 350 KVA, 276/480 volts. DC Generator: Lincoln "Idealarc" DC-600. Air Compressor: Ingersoll Rand 4.2 m^3/min (150 ft^3/min) capacity.		
Zinc Wire Size, millimeters (inches)	3.175 (0.125)	3.175 (0.125)
Number of Metallizing Guns Used	1	1
Type of Wire/Purity	Zinc, 99%	Zinc, 99%
Metallized Zinc Output, kg/hr (lb/hr) Lane 1 Lane 2	 – –	 39.2 (86.5) 25.2 (55.7)**
Gun Tip to Surface Distance, millimeters (inches)		203 to 305 (8 to 12)
Arc Metallizing Gun Power Output: DC Volts, Lane 1 Lane 2 Amperes, Lane 1 Lane 2	 – – – –	 25.6 29.2 488.5 252.6**
Zinc Deposit Efficiency, %, Lane 1 Lane 2	66 66	52.5 64.2
Stripe Width, millimeters (inches)	152 (6)	152 (6)
Stripe Spacing, millimeters (inches) O.C.	305 (12)	305 (12)
Avg. Stripe Thickness, millimeters (inches), Lane 1 Lane 2	0.610 (0.024) 0.610 (0.024)	0.508 (0.020)* 0.610 (0.024)*
Number of Passes with Gun	–	16
Deposit Zinc Weight, kg/m^2 (lb/ft^2) Concrete Lane 1 Lane 2	 2.44 (0.50) 2.44 (0.50)	 2.05 (0.42) 2.44 (0.50)
Gun Traversing Speed, millimeters/seconds (inches/second)	610 (24)	610 (24)
Ambient Air Temperature During Metallizing, °C (°F)	–	38+ (100+)

* Density of sprayed zinc is 89% of the original wire[10]

** Lane 2 area was metallized first. Low amperage setting and low metallizing gun output reflects the

AC OVERLAY: An asphalt concrete overlay with polyester reinforcing fibers, as described in Appendix 10.6, was placed in two lifts over the metallized zinc distribution anode grid and the nonconductive clear areas surrounding each CP zone (Figure 5.4-I). Prior to applying the AC overlay, a light tack coat of liquefied asphalt emulsion (RS-1) was sprayed (0.02 to 0.10 gal/yd^2) on the concrete/zinc surface to serve as a bond coat for the AC overlay.

The AC overlay was applied thicker than normal; average thickness was 107.95 mm (4.25 inches) to match the grade of the overlay for the adjacent Coke Breeze CP system which was installed on the same structure.

The same equipment and compaction procedures were used to install the overlay for this system as was described in Section 5.3 for the Coke Breeze CP system.

C. Installation Testing

Short circuit monitoring was performed during the metallizing process. A high impedance voltmeter (set on a low voltage DC scale), connected between the zinc stripe being sprayed and the reinforcing steel mat, continuously monitored the voltage during the spraying process. If no short circuits were detected during the spraying process, the voltmeter displayed an open circuit potential. If a metallic path were encountered, then the display would read "zero", indicating electrical continuity and the metallizing operation would be stopped immediately to search for the short circuit path.

One short circuit was found during the metallizing operation. It was caused by an exposed area of rebar which was not visible from the surface. This area of rebar was exposed to the surface through a crack in the deck concrete, but it was too deep within the concrete for the short circuit tester to find during the short circuit testing. Instead, this short was found during the short circuit monitoring procedure described in the previous paragraph. When the metallizing spray gun passed over the crack, the sprayed zinc contacted the exposed rebar and the monitored voltage potential immediately dropped to "0". The spraying was stopped at that point and the metallic contact was located. The short was corrected by removing the zinc and isolating the contact area from the remainder of the zinc stripe. The bare spot was covered with nonconductive epoxy to further isolate it.

After the metallizing was completed, 87 zinc samples, each approximately 25 mm (1 in) in diameter, were removed from the stripes to determine the amount of zinc actually applied to the deck.

D. Summary of System Components

The components of the Metallized Zinc CP system are shown in Table 5.4-B.

Table 5.4-B

Metallized Zinc CP System Components
Upper Salt Creek UC (Left)

COMPONENT	DESCRIPTION	INSTALLATION
CP System	Two independent zones separated by 0.6 m (2 ft) wide clear area, Total anode area = 191.6 m^2 (2062.1 ft^2)	Installed: Summer of 1988. Energized: November 1988.
Primary Anodes	Eight total: Seven 50 mm x 50 mm x 9.5 mm (2 in x2 in x3/8 in) thick brass pads, and one #8 HWMPE insulated wire (Experimental).	Brass pads epoxied flush with deck with wires extending through the deck. Four anodes in zone 2, three in zone 1. One experimental wire anode in zone 1. Wire extended up through the deck, wire strands spread and encapsulated in zinc stripe during spraying process.
Distribution Anode	152 mm (6 in) wide, 0.51 mm (0.02 in) thick metallized zinc stripes spaced transversely on 305 mm (12 in) centers connected by 4 longitudinal stripes to form a grid pattern for each zone.	Portable hand- held arc-spray metallizing equipment *: 16 passes per stripe; portable wooden template used as guide.
Overlay	107.95 mm (4 1/4 in) thick AC with polyester reinforcing fibers (Bonifibers).	Conventional paving equipment. Extra thickness needed to match grade of adjacent Coke Breeze AC overlay.
Rectifier	Constant voltage, 20 volts DC, 5 amperes capacity.	System rewired to existing rectifier.
Rebar Ground Connections	Two independent #8 gauge wire leads.	CADWELDED to rebar mat at two places on opposite ends of structure.

(*) See Table 5.4-A for Arc Metallizing Parameters.

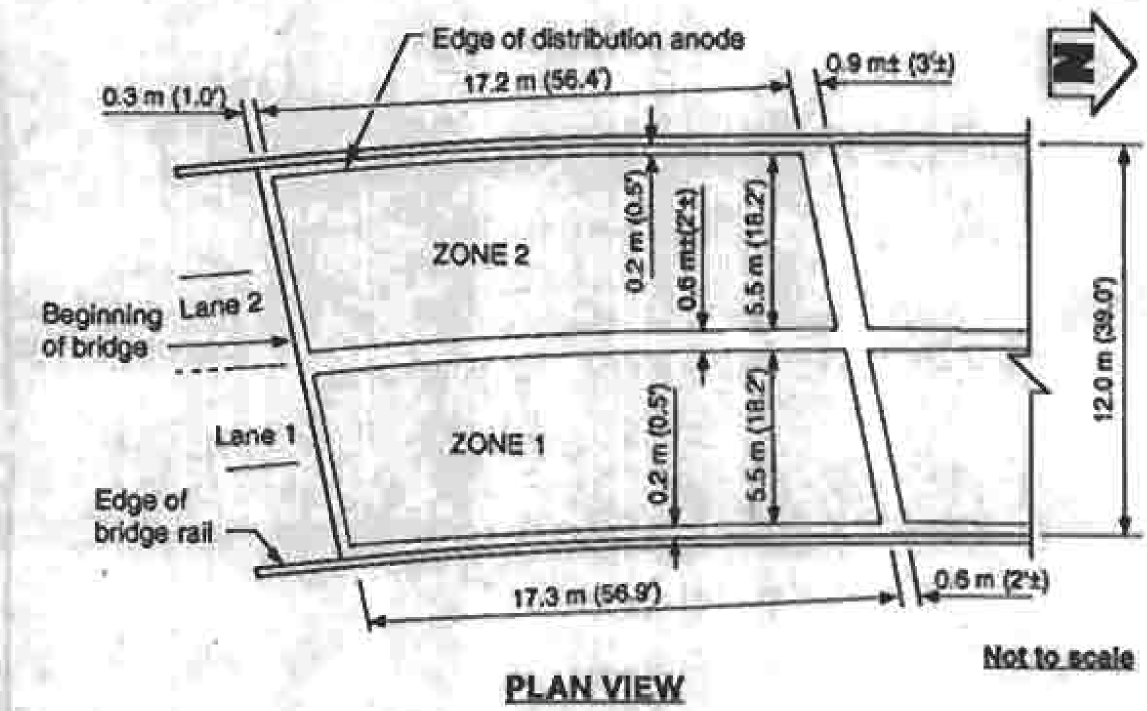


FIGURE 5.4-A Location and Dimensions of Distribution Anode for Metallized Zinc CP System (Zones 1 & 2), Upper Salt Creek UC (Left)

FIGURE 5.4-B Deck Brass Pad Primary Anode for Metallized Zinc CP System, Upper Salt Creek UC (Left)

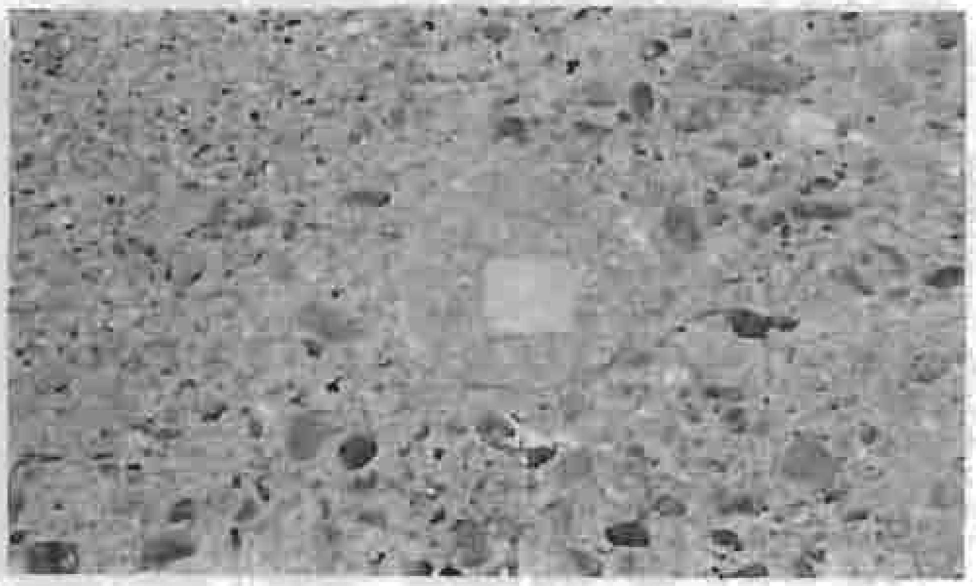


FIGURE 5.4-C Brass Pad Primary Anode in Place, Metallized Zinc CP System, Upper Salt Creek UC (Left)

FIGURE 5.4-D Exposed #8 Gauge Wire Primary Anode Contact, Metallized Zinc CP System, Lane 1, Upper Salt Creek UC (Left)

FIGURE 5.4-E Metallized Zinc Distribution Anode Grid Pattern, Upper Salt Creek UC (Left)

FIGURE 5.4-F Typical Metallized Zinc Grid Pattern Over Brass Pad Primary Anode, Upper Salt Creek UC (Left)

FIGURE 5.4-G Typical Stainless Steel #10-32 Screw Electrical Contact on Brass Pad, Upper Salt Creek UC (Left)

FIGURE 5.4-H Epoxy Coating Over #10-32 Screw Electrical Contacts on Brass Pad Primary Anode, Upper Salt Creek UC (Left)

FIGURE 5.4-I Placing AC Overlay on Metallized Zinc Distribution Anode, Upper Salt Creek UC (Left)

5.5 RAYCHEM "FEREX 100" CP SYSTEM

A. General Operation

The Raychem "Ferex 100" CP system was installed on the northern half of the Upper Salt Creek UC (Right) bridge deck. The total surface area of the distribution anode was 206.5 m² (2223 ft²). This impressed current system delivers CP current from the rectifier directly to a "Ferex 100" cable which is functionally unique because this cable serves as both the primary anode and the current distribution anode. The Ferex cable is a copper coated wire with a conductive polymer coating, which forms a continuous flexible anode. The continuous anode cable is attached to the bridge deck with plastic cleats to form a mesh, which looks like a series of loops. From the Ferex cable, current flows through the deck surface to the reinforcing steel within the concrete. A low slump concrete overlay is used to protect the cable from traffic wear.

B. Installation

Figure 5.5-A shows the configuration of the Raychem "Ferex 100" CP system which consists of two independent zones separated by a 0.6 m (2 ft) nonconductive strip. The two zones of this CP system were later connected together through the wiring system to a common rectifier.

This is a proprietary CP system. Although the design and installation procedures were provided by the manufacturer, some deviations were made from that design. Caltrans initiated a change order to increase the thickness of the concrete overlay and to include a #10M epoxy coated reinforcing steel mat within the overlay, so that the overlay could withstand the high traffic volume and heavy truck loads characteristic of this major north-south Interstate route.

Since the overlay reinforcing steel mat was placed near the distribution anode, there was concern that stray current from the deck CP system would result in damage to this reinforcing steel. For this reason, the overlay reinforcing steel mat was protected by a separate CP system through a separate rectifier. The overlay CP system used the same distribution anode as the deck CP system for the delivery of current.

After the deck was prepared and sandblasted, the Raychem "Ferex 100" CP system was installed in three phases: (1) the "Ferex 100" anode cable was laid out and fastened to the bridge deck; (2) the anode cable was connected to the rectifier supply cable; and (3) the reinforced concrete overlay was placed.

ANODE CABLE INSTALLATION: The anode cable was laid out on the deck surface in a looped pattern longitudinal to the length of the structure (Figure 5.5-B). The anode cable used for each CP zone was a single, continuous cable that started and terminated at the same supply wire from the rectifier. In this manner, the resulting anode cable grid became the CP current delivery source.

Nonconductive, 6.35 mm (1/4 in) diameter, plastic cleats, pushed into pre-drilled holes in the concrete deck at 3 m (10 ft) intervals, held the anode strands in place on the deck surface. Special conductive cleats, spaced at intermediate points along the strand length and at the ends of the loop, were also added to allow parallel cables to be interconnected electrically. Conductive cleats formed multiple electrical paths within each zone and reduced the line resistance of the anode strands within each zone.

Manufacturer supplied splice connections were used to butt splice the conductive "Ferex 100" anode cables to the #8 HMWPE insulated supply wire (Figure 5.5-C). The #8 gauge HMWPE wire extended through existing cored holes in the deck and was in turn connected to #10 AWG wires to the rectifier box located under the bridge.

PLACING THE OVERLAY REBARS: One mat of #3 sized epoxy coated reinforcing steel bars were placed 38.1 mm (1-1/2 in) above the distribution anode cables to add structural strength to the concrete overlay. The overlay rebar was placed in a grid pattern at a spacing of 305 mm (12 in) on center.

The overlay reinforcing steel mat for the Raychem "Ferex 100" CP system and the overlay reinforcing steel mat for the Eltech "Elgard 210" CP system (described in Section 5.6) were kept separated. The reinforcing steel in the clear area between the Raychem and the Eltech CP systems was staggered and overlapped in such a way that no overlay reinforcing steel from the adjacent CP systems was touching. In this way, the continuity of the reinforcement in the concrete overlay could be maintained without having any electrical continuity between the two overlay mats.

The reinforcing steel in the concrete overlay was protected by a CP system that discharged CP current from the same distribution anode as that used by the deck CP system, although separate rectifiers were used. This was accomplished by using the circuit shown in Figure 5.5-D.

A #8 gauge HMWPE insulated wire lead was CADWELDED to the overlay reinforcing steel mat and extended through the cored hole in the deck. This was then connected to the wiring system for the Raychem overlay rectifier.

In order to guarantee electrical continuity within the overlay rebar mat, one longitudinal and one transverse rebar was welded at each intersection (Figure 5.5-E). Additionally, each transverse rebar length between the two zones was welded to maintain electrical continuity across the full width of the bridge deck. All welded connections were coated in the field with epoxy before the concrete overlay was placed.

PLACING THE PCC OVERLAY: The controlled slump concrete overlay, average thickness of 99.1 mm (3.9 in), was designed and placed in accordance with the specifications reprinted in Appendix 10.7. The #3 epoxy coated reinforcing steel mat used in the overlay is not included in these specifications since it was added during construction as a construction change order (CCO).

Figure 5.5-F shows the placement of the reinforcing steel mat over the "Ferex 100" anode cables. Figure 5.5-G shows the low slump concrete being placed.

C. Installation Testing

Short circuit monitoring was conducted while the concrete overlay was being placed. This testing was performed similar to the procedure used during the metallizing process, except that in this case, two high impedance voltmeters (each set on a low voltage DC scale) were used. One voltmeter was connected between the bridge deck reinforcing steel mat and the distribution anode cable, and the second voltmeter was connected between the low slump concrete overlay reinforcing steel mat and the same distribution anode cable. If no short circuit existed or occurred, the voltmeters displayed an open circuit potential. If an electrical path was encountered, the display would read "zero", indicating electrical continuity.

No short circuits were found during the concrete placement. After the concrete overlay cured for one day, the system was again checked for short circuits. Again, none were found.

In order to provide cathodic protection to the epoxy coated overlay steel, the following assumptions were made to estimate the amount of exposed steel surface area used to set the current density requirements: (a) A worst-case condition where two percent of the rebar surface area had pre-existing damage[11], (b) Thirty percent of all wire tied intersections of the rebar may have some level of chaffing damage caused by workers walking on or moving equipment over the steel mat prior to placing of concrete, and (c) The assumed total area of chafing damage at each intersection was approximately 6.45 mm^2 (0.01 in^2), conforming to the approximate contact surface of two intersecting #3 reinforcing bars.

D. Summary of System Components

The components of the Raychem "Ferex 100" CP system are given in the Table 5.5-A.

Table 5.5-A

Raychem "Ferex 100" CP System Components
Upper Salt Creek UC (Right)

COMPONENT	DESCRIPTION	INSTALLATION
CP System	Two independent zones separated by a 0.6 m (2 ft) wide clear area. Total anode area = 206.5 m^2 (2223 ft^2).	Installed: Summer 1988 Energized: November 1988.
Primary/Distribution Anode	Continuous 7.87 mm (0.31 in) dia. strand of conductive polymeric anode coating on copper wire.	Attached to concrete deck with plastic clips. Cable looped back and forth across deck at approx. 203 mm (8 in) spacing. Connected with 8 gauge wires with HWMPE insulation, extending through the deck to the rectifier.
PCC Overlay	99.1 mm (3.9 in) thick, low-slump, high-density PCC concrete.	Conventional concrete paving equipment used to install protective traffic wear course over anode.
PCC Overlay Reinforcing	Epoxy coated #3 rebar mat placed 305 mm (12 in) O.C. approx. 38.1 mm (1.5 in) clear of bridge deck.	Used to strengthen overlay to withstand heavy traffic loads. Installed independently of deck rebar and protected with separate CP system using same distribution anode as deck CP system.
Rectifier, Deck Reinforcing	Constant voltage, 20 volts DC, 5 amperes capacity.	System wired to existing rectifier. Supplies CP current from Raychem "Ferex 100" anode strands to bridge deck reinforcing steel.
Rectifier, PCC Overlay Reinforcing	Constant voltage, 20 volts DC, 5 amperes capacity.	System wired to existing rectifier. Supplies CP current from Raychem "Ferex 100" anode strands to overlay reinforcing steel mat.
Deck Rebar Ground Connections	Two independent #8 gauge wire leads.	CADWELDED to deck rebar mat at two places at opposite ends of structure.
Overlay Rebar Ground Connection	One #8 gauge wire lead.	CADWELDED to overlay rebar mat.

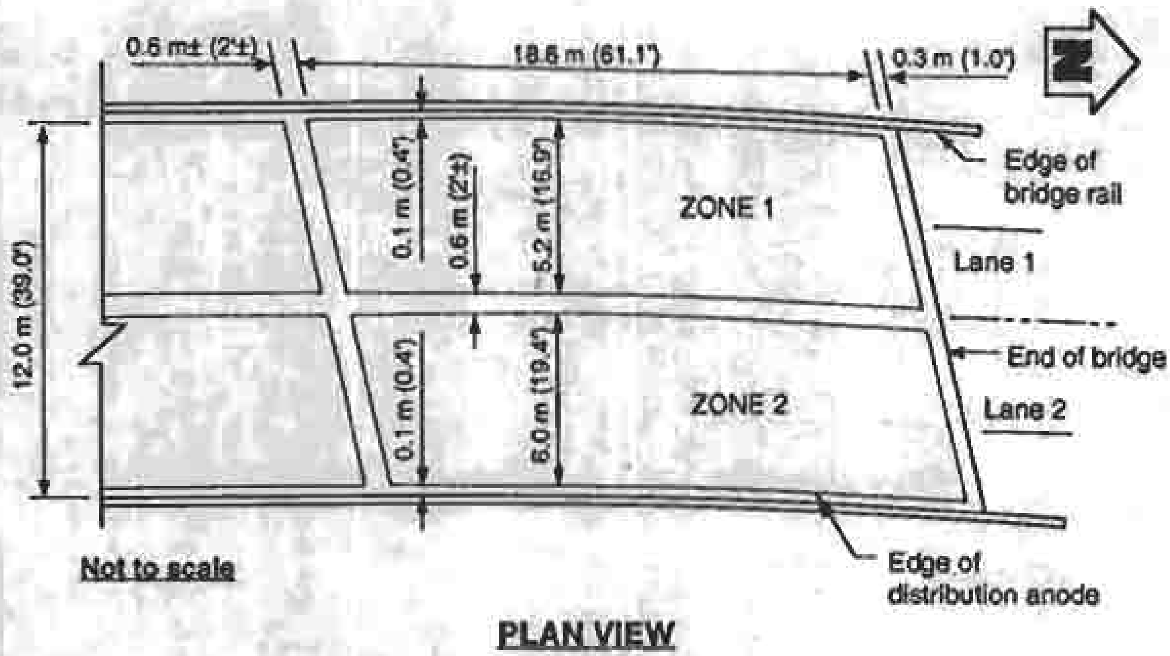


FIGURE 5.5-A Location and Dimensions of Distribution Anodes for Raychem "Ferex 100" CP System (Zones 1 & 2), Upper Salt Creek UC (Right)

FIGURE 5.5-B Primary Anode Placement, Raychem "Ferex 100" CP System, Upper Salt Creek UC (Right)

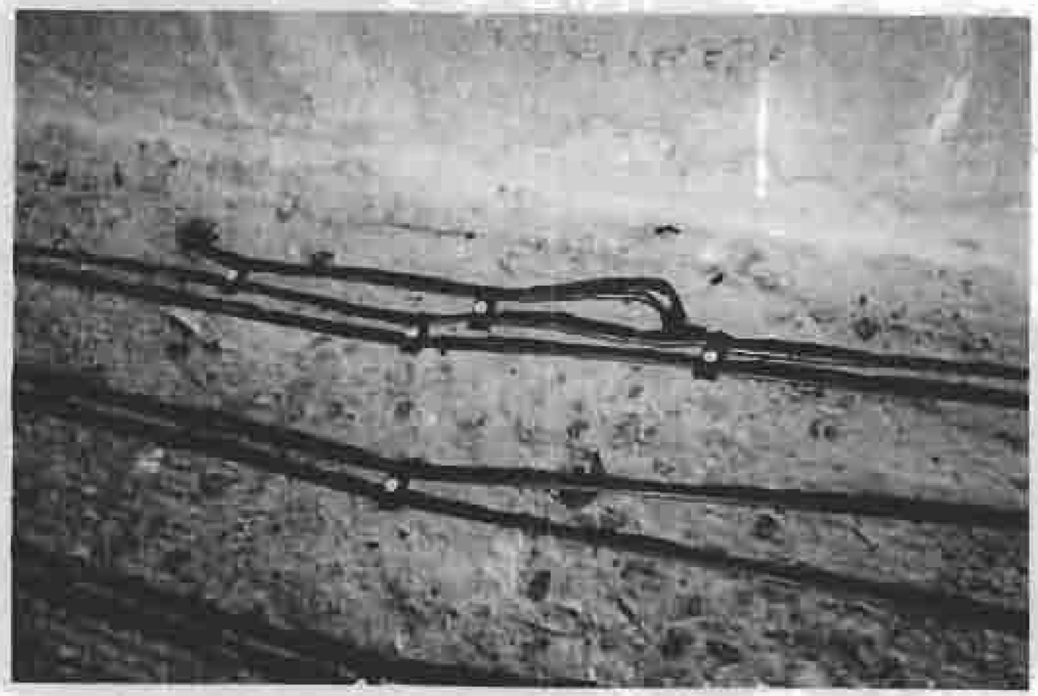


FIGURE 5.5-C Field Splice Connection, Raychem "Ferex 100" Distribution Anode, Upper Salt Creek UC (Right)

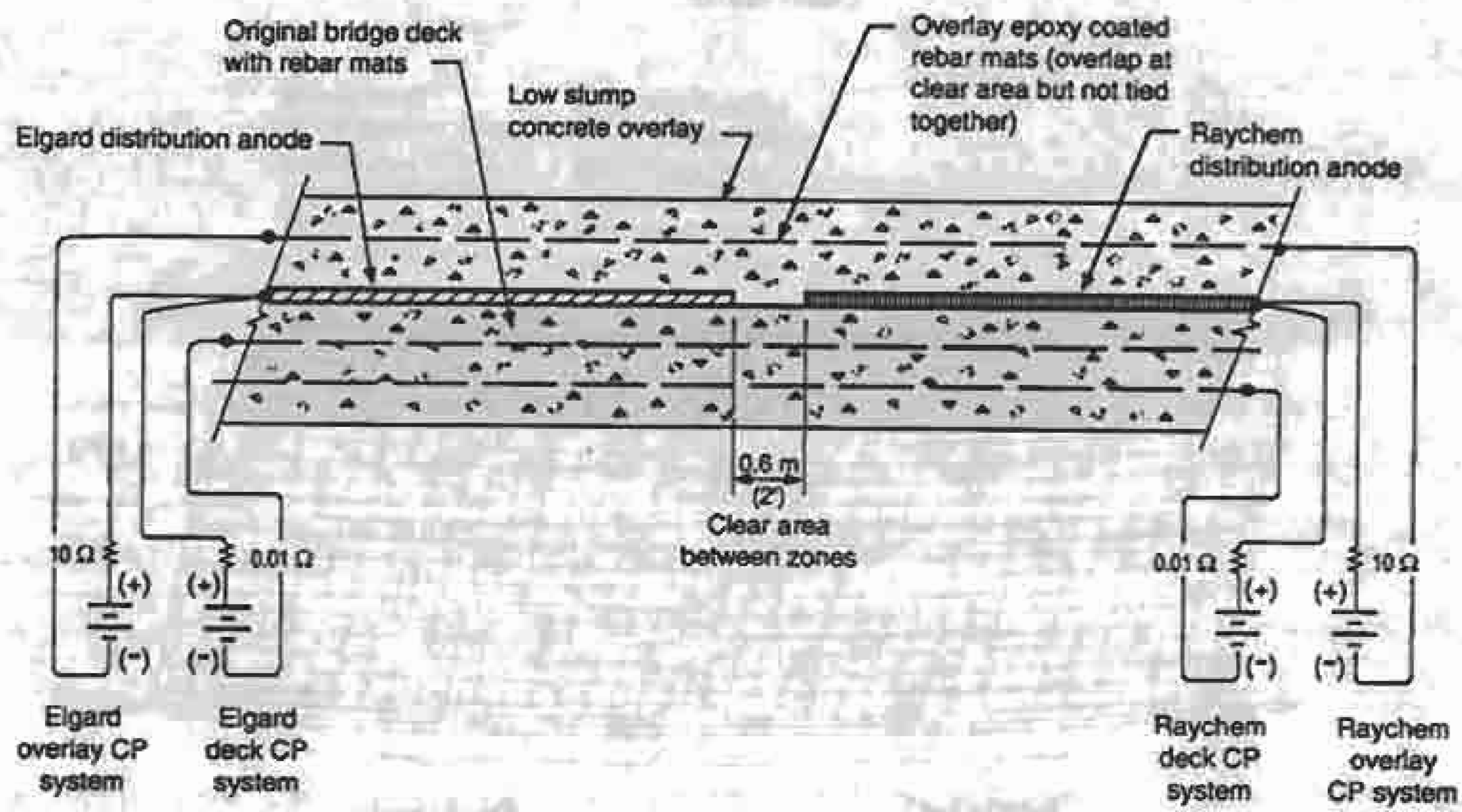


FIGURE 5.5-D Typical Cross Section Schematic of Raychem and Eltech CP Systems Design, Upper Salt Creek UC (Right)

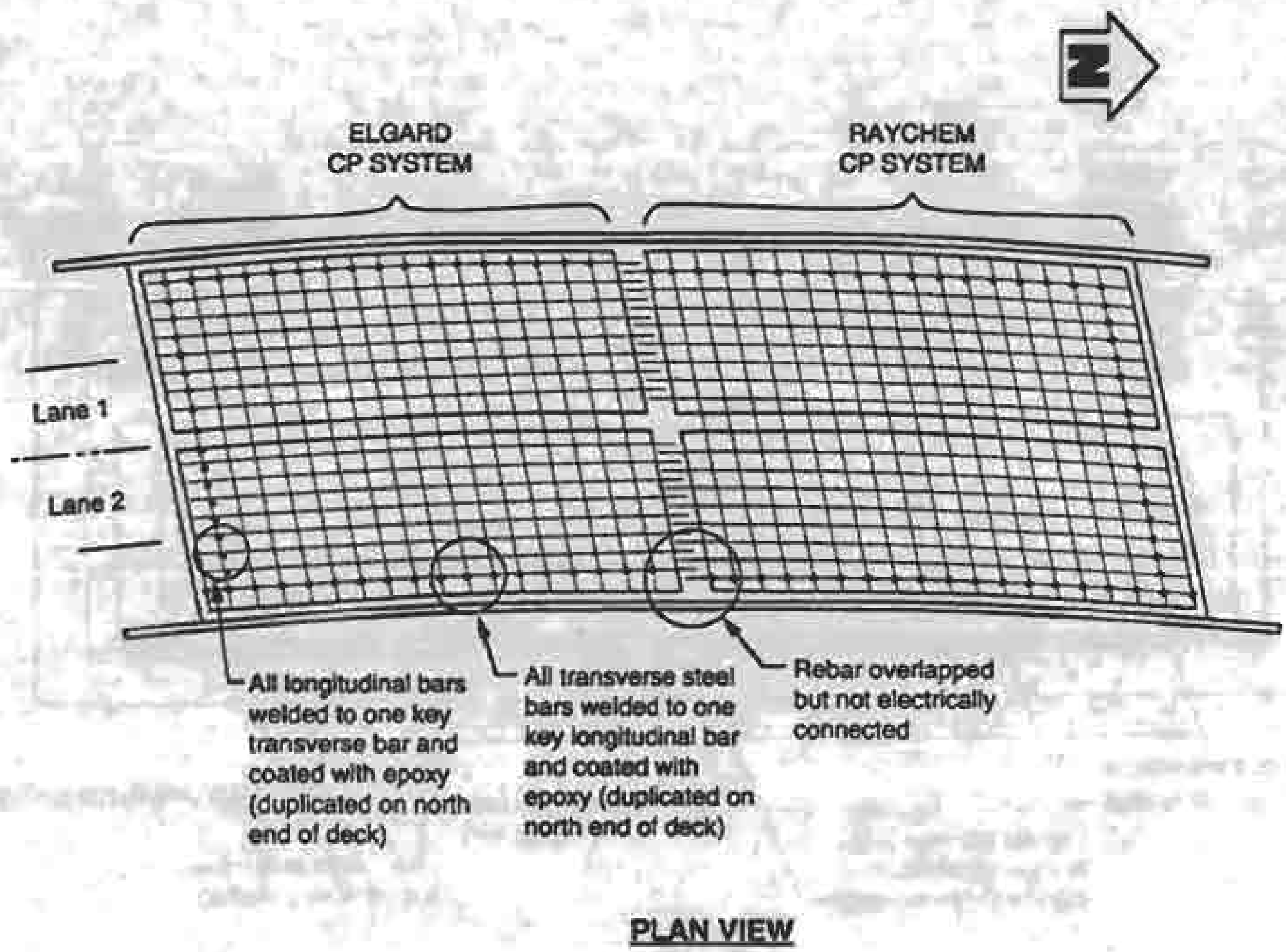


FIGURE 5.5-E Typical Format for Overlay Reinforcing Steel, Upper Salt Creek UC (Right)

FIGURE 5.5-F Epoxy Coated Reinforcing Steel Over Raychem "Ferex 100" Distribution Anode, Upper Salt Creek UC (Right)

FIGURE 5.5-G Placing Low Slump Concrete Over Raychem and Eltech CP Systems, Upper Salt Creek UC (Right)

5.6 ELTECH "ELGARD 210" CP SYSTEM

A. General Operation

The Eltech "Elgard 210" CP system was installed on the southern half of the Upper Salt Creek UC (Right) bridge deck. The total surface area of the distribution anode applied was 198.4 m^2 (2136 ft^2). This impressed current CP system delivers CP current from the rectifier to titanium ribbon distributor bars which serve as the primary anodes for the system. The distributor bars deliver the current to the Elgard titanium mesh which in turn distributes the CP current across the surface of the deck and then to the reinforcing steel in the deck. A low slump concrete overlay was installed to protect the mesh from traffic wear.

B. Installation

Figure 5.6-A shows the configuration of the Eltech "Elgard 210" CP system which consists of two independent zones separated by a 0.6 m (2 ft) nonconductive area. As with the Raychem "Ferex 100" CP system, Caltrans changed the design of the Eltech system to include a thicker concrete overlay, which was reinforced with a #3 epoxy coated reinforcing steel mat. Cathodic protection was also provided to this overlay reinforcing steel mat to guard against the possibility of stray current damage. The two zones of this CP system were later connected together through the wiring system to a common rectifier.

After the deck was prepared and sandblasted, the Eltech "Elgard 210" CP system was installed in four phases: (1) The current distributor bars were placed; (2) The anode mesh was laid out and anchored to the concrete bridge deck; (3) The anode mesh was spotwelded to the distributor bars; and (4) The reinforced concrete overlay was placed.

CURRENT DISTRIBUTOR BAR PLACEMENT: The current distributor bars, 12.7 mm x 1.02 mm (0.5 in x 0.04 in) thick strips of oxide coated titanium, were placed transversely under the mesh at the southern end of each CP zone, approximately 1.5 m (5 ft) from the end of the deck. After the rolls of mesh were placed, the distributor bars and mesh wire was resistant spotwelded at each mesh intersection, spaced at approximately 76 mm (3 in) intervals along the distributor bar (Figure 5.6-B).

Each distributor bar was bent down through 38.1 mm (1-1/2 in) diameter holes cored through the bridge deck, located near the southwest and southeast corners of the bridge. The ends of the bars were silver soldered to #10 AWG insulated copper wires which extended to the rectifier box located under the bridge. The distributor bars, silver soldered connections, and wire leads which passed through the cored holes were insulated from the concrete with shrink tubing insulation and nonconductive epoxy.

ANODE MESH INSTALLATION: Nine rolls of "Elgard 210" titanium wire mesh were used as the distribution anode for the Eltech "Elgard 210" CP system. The Elgard anode mat is made of expanded-flattened titanium steel mesh with strand size of 1.59 mm (1/16 in) width by 0.79 mm (1/32 in) thick. The diamond shaped mesh opening were 76 mm (3 in) long by 33.0 mm (1.3 in) wide. Five anode mats, each 1219 mm (48 in) in width, were installed to a length of 17.8 mm

(58.4 ft) in zone 2 and four anode mats with the same dimensions were installed in zone 1 (Figure 5.6-C).

The anode mesh was rolled out longitudinally and then fastened to the deck with plastic cleats ("T" shaped) which were driven into 4.76 mm (3/16 in) diameter, 12.70 mm (1/2 in) deep predrilled holes in the concrete deck. Originally, the cleats were placed every 0.91 m to 1.07 m (3 to 3.5 ft), however, the construction crew and other movement on the deck caused some of these areas to become loose and the mesh anode became stretched. Additional plastic cleats were used to secure those areas of the anode mesh to the deck.

PLACING THE OVERLAY REBARS: The same procedure as described in Section 5.5 (Raychem "Ferex 100" CP system) was used to install the epoxy coated overlay reinforcing steel. Figure 5.6-D shows the epoxy coated reinforcing steel mat being placed over the "Elgard 210" anode mesh.

In 1997, it was discovered that there was some corrosion of the epoxy-coated reinforcing steel in the Elgard overlay section. The cause for this corrosion is unknown at this time, but is being investigated further.

PLACING THE PCC OVERLAY: The controlled slump concrete overlay, average thickness of 96.5 mm (3.8 inches), was prepared and placed as described in Section 5.5 (Raychem "Ferex 100" CP system overlay). Refer to that section for design and installation descriptions.

C. Installation Testing

Short circuit monitoring was conducted between the "Elgard 210" mesh and the bridge deck reinforcing steel mat during the placement of the concrete overlay. This testing was performed in the same manner as for the Raychem "Ferex 100" CP system overlay (described in Section 5.5).

A short circuit was detected during the placement of the concrete overlay in zone 2. An anchor bolt used to hold the concrete grade form in place was accidentally placed in contact with the deck reinforcing steel mat. During the placement of concrete, the anode mesh shifted and came in contact with the anchor bolt, resulting in a direct short between the rebar mat and the anode mesh. This was soon located and a small section of the anode mesh was cut out to clear the bolt. No other short circuits were found.

D. Summary of System Components

The components of the Eltech "Elgard 210" CP system are shown in Table 5.6-A.

Table 5.6-A

Eltech "Elgard 210" CP System Components
Upper Salt Creek UC (Right)

COMPONENT	DESCRIPTION	INSTALLATION
CP System	Two independent zones separated by 0.6 m (2 ft) wide clear area. Total anode area = 198.4 m^2 (2136 ft^2).	Installed: Summer 1988 Energized: November 1988.
Primary Anode	Two titanium ribbon strips 12.7 mm x 1.02 mm (0.5 in x 0.04 in) thick.	Spotwelded every 76 mm (3 in) to titanium mesh anode to transfer CP current from rectifier lead to mesh anode.
Distribution Anode	Metal oxide coated titanium mesh anode. Nine, 1.2 m (4 ft) wide rolls.	Mesh anode unrolled to a length of 17.8 m (58.4 ft) and attached to the deck with plastic fasteners approx. 0.9 m (3 ft) apart.
PCC Overlay	96.5 mm (3.8 in) thick low-slump, high-density PCC concrete.	Conventional concrete paving equipment used to install protective traffic wear course over anode.
PCC Overlay Reinforcing	Epoxy coated #3 rebar mat placed 305 mm (12 in) O.C., approx. 38.1 mm (1.5 in) clear of bridge deck.	Used to strengthen overlay to withstand heavy traffic loads. Installed independently of deck rebar and protected with separate CP system using same distribution anode.
Rectifier, Deck Reinforcing	Constant voltage, 20 volts DC, 5 amperes capacity.	System wired to existing rectifier. Supplies CP current from mesh anode to bridge deck reinforcing steel.
Rectifier, PCC Overlay Reinforcing	Constant voltage, 20 volts DC, 5 amperes capacity.	System wired to existing rectifier. Supplies CP current from mesh anode to bridge deck reinforcing steel.
Deck Rebar Ground Connection	Two independent #8 wire leads.	CADWELDED to deck rebar mat at two places on opposite ends of structure.
PCC Overlay Rebar Ground Connection	One #8 wire lead.	CADWELDED to overlay rebar mat.

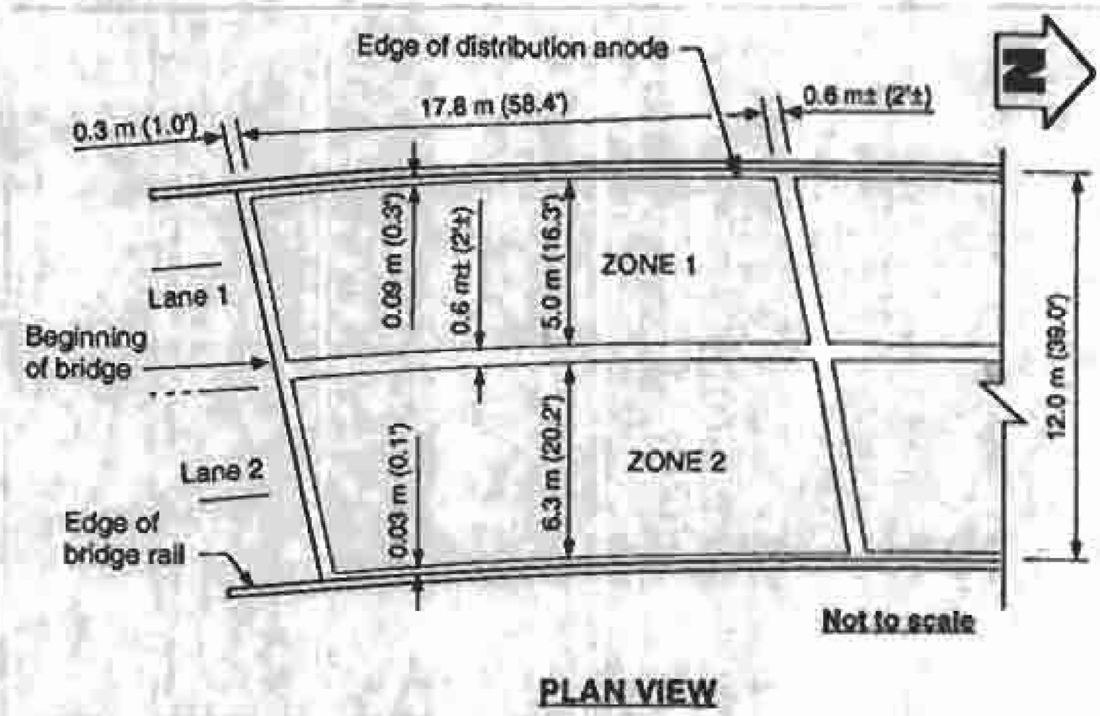


FIGURE 5.6-A Location and Dimensions of Distribution Anodes for Eltech "Elgard 210" CP System (Zones 1 & 2), Upper Salt Creek UC (Right)

FIGURE 5.6-B Current Distribution Strip in Place for Eltech "Elgard 210" CP System, Upper Salt Creek UC (Right)

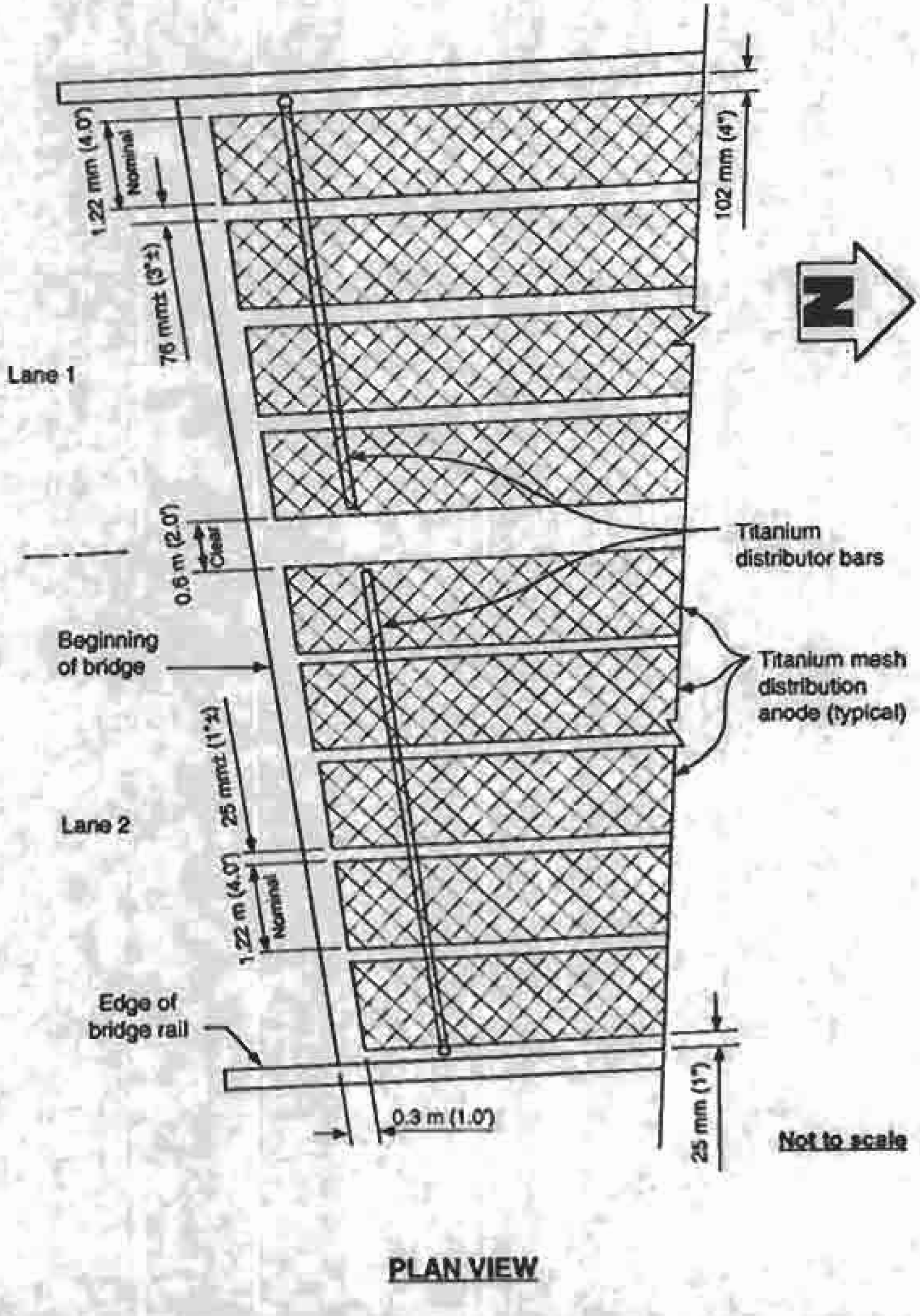


FIGURE 5.6-C Distribution Anode Mesh Panels for Eltech "Elgard 210" CP System, Upper Salt Creek UC (Right)

FIGURE 5.6-D Typical Placement of Reinforcing Steel Mat Over Eltech "Elgard 210" Distribution Anode Mesh, Upper Salt Creek UC (Right)

5.7 CONDUCTIVE POLYMER CP SYSTEM

A. General Operation

The Conductive Polymer CP system, developed by Caltrans in 1988, was installed on the O'Brien UC (Left) bridge deck. The total surface area of the deck receiving the distribution anode was 377.1 m^2 (4058.8 ft^2). Unlike the other systems presented in this study, this impressed current CP system used a conductive polymer overlay which functions as both the distribution anode and the wearing surface for traffic. An electrical bus bar (a bare #3 reinforcing bar) connected to an 8 gauge steel wire primary anode mesh, both of which are encapsulated in the conductive polymer distribution anode overlay, receives CP current from the rectifier. From the overlay, protective CP current is distributed across the bridge deck and down to the reinforcing steel.

B. Installation

Separated by 0.6 m (2 ft) nonconductive areas, the conductive polymer overlay was installed in four independent quadrants (Figure 5.7-A). Since this was the first deck installation of this system, these zones were not tied together electrically so that they could be monitored independently via their own CP circuit. Each zone was wired separately to a different rectifier.

The Conductive Polymer CP system was installed in four phases: (1) A conductive primer bond coat was applied to the bridge deck; (2) Steel wire mesh and a bus bar were placed and anchored to the deck; (3) A conductive polymer overlay was placed; and (4) The nonconductive areas separating the four quadrants were filled with a nonconductive primer and a nonconductive overlay mix.

CONDUCTIVE PRIMER BOND COAT APPLICATION: A conductive primer bond coat was used between the polymer overlay and the concrete deck to attach the overlay to the deck and to overcome the thermal expansion differences between these two materials. After the deck was prepared, the conductive primer was applied with stiff bristle push brooms and paint rollers at a rate of 0.815 L/m^2 (1 gal/50 ft^2) of deck surface, approximately 0.79 mm (1/32 in) thick. The primer mix (by weight) consisted of two parts of graphite flakes, which provided the conductive characteristics necessary for CP, and three parts of polyester resin, which served as the binder.

STEEL WIRE ANODE MESH AND BUS BAR PLACEMENT: After the conductive primer had been applied and cured to a tack-free state, an 8 gauge, 152 mm by 152 mm (6 in by 6 in), W2 X W2 steel welded-wire mesh was placed. Multiple panels of the wire mesh were cut and joined end-to-end (with wire ties) to form one electrically continuous blanket of mesh within each CP zone. The wire mesh primary anode was secured to the concrete deck with nonconductive plastic anchors driven into 6.35 mm (1/4 in) diameter predrilled holes in the deck (Figure 5.7-B). The drilled holes were blown clean of any primer residue before the plastic pins were inserted so that no conductive path would exist between the primer coat or conductive overlay and the reinforcing steel mat in the deck.

The plastic anchors for the Lane 2 zone installation (the first to be installed) were spaced at approximately 0.6 m (2 ft) centers in order to maintain a 3.18 mm to 4.76 mm (1/8 to 3/16 in) clearance between the wire mesh and the conductive primer surface. An improved clearance technique was used on the second installation (lane #2). Plastic spacers were placed on the wire mesh strands to maintain that clearance from the deck (Figure 5.7-C). This technique allowed the wire mesh plastic anchor spacing to be increased to 1.8 m (6 ft) centers.

The plastic spacers were made of short segments, approximately 19.1 mm (3/4") long, of flexible plastic tubing 3.175 mm (1/8") inside diameter and 3.175 mm (1/8") wall thickness. The tubing segments were cut lengthwise so they could be slipped over the wire mesh strands at locations where the wire was in contact with the conductive primer.

After the wire mesh was placed and anchored, a #10M (#3) reinforcing steel distributor bar (bus bar) was wire tied to the wire mesh along the shoulder edge of each zone to provide uniform CP current distribution to the wire mesh (Figure 5.7-D). The distributor bars for each quadrant were CADWELDED to a #8 gauge HWMPE insulated wire which extended through a 38.1 mm (1-1/2 in) diameter cored hole in the deck to their respective rectifier (Figure 5.7-E). The cored holes were located within the nonconductive overlay areas at the extreme ends of the deck adjacent to each quadrant. The CADWELDED area was wrapped with rubber electrical insulation tape and then further insulated with nonconductive epoxy.

CONDUCTIVE POLYMER DISTRIBUTION ANODE OVERLAY PLACEMENT: The design thickness for the conductive polymer overlay was 31.75 mm (1 1/4 in), however, the "as-built" thickness varied between 34.9 to 50.4 mm (1-3/8 to 2 in), averaging 43.43 mm (1.71 in). This difference was due to the irregular surface of the bridge deck and the Resident Engineer's requirement to match the grade of the bridge deck approach slab. The conductive polymer overlay was placed similarly to a concrete overlay, except that the polymer was mixed on site and wheelbarrowed to the pour. This procedure was required since the gel time of the polymer mix was approximately 20 minutes. The polymer mix had to be placed, compacted, and leveled within that time period. Three 0.25 m^3 (9 ft^3) concrete mixers working in sequence were used to maintain a continuous flow of mix for the deck overlay.

As the polymer overlay was placed, it was leveled and compacted with an air driven "Allen Air Screed, Model 12" vibrator strike-off machine. All other equipment used for the pour was similar to that needed for conventional concrete. Sand was broadcast onto the finished surface before the deck was cured to provide additional roughness to increase the skid resistance.

The conductive polymer overlay mix consisted of the following materials as presented in Table 5.7-A:

Table 5.7-A

Conductive Polymer Overlay Components
O'Brien UC (Left)

COMPONENT	QUANTITY
"Lonestar" Monterey B11 Sand	45.3 kg (100 lbs)
Pea Gravel, B39	45.3 kg (100 lbs)
Coke Breeze, Asbury # 214	45.3 kg (100 lbs)
Fluid Petroleum Coke Breeze, Asbury # 251	15.0 kg (33 lbs)
Polyester Styrene Resin	30.8 kg (68 lbs)
MEKP Catalyst:	
Lane #1 (or, 1% by vol. of resin)	0.25 kg (9 oz)*
Lane #2 (or, 1/2% by vol. of resin)	0.14 kg (5 oz)*

* This amount was adjusted to compensate for the effect of differing summer temperatures during placement.

Two problems arose during the placement of the conductive polymer overlay. The first problem was a result of inconsistent mixing by the contractor. Several times the contractor did not thoroughly mix the polyester resin and the initiator prior to adding the aggregate. During the mixing of one batch, initiator was not added to the conductive polymer. This inconsistent mixing resulted in a section of uncured conductive polymer. The contractor was required to tear out this section and replace it. The contractor sawcut the section and removed the polymer and wire mesh contained in it. A new piece of wire mesh was placed and the section was backfilled with properly mixed conductive polymer.

The second problem occurred at the end of the SW quadrant. The contractor discovered the polyester resin had started to harden due to improper storage. The result was resin could not be used and the last 2.75 m (9 ft) could not be completed. The contractor obtained new polyester resin and completed the quadrant two weeks later by first reinstalling the conductive prime coat and then placing the overlay.

INSTALLING NONCONDUCTIVE SEPARATIONS: When the conductive polymer overlay cured and the forms were removed, the clear area between each zone was filled with a nonconductive polymer mix and finished to grade to match the conductive polymer overlay. The clear areas were filled in stages to due to traffic control requirements.

A nonconductive primer similar to the conductive primer coat, but without graphite, was applied in the areas separating the four independent quadrants at a rate of 1 L/17.6 m^2 (1 gal/80 yd^2) of concrete surface area. The nonconductive polymer overlay was placed after the nonconductive primer cured to a tack-free state. The nonconductive overlay was mixed in the same manner as the conductive overlay, but was hand leveled and compacted.

The nonconductive polymer overlay mix consisted of the following materials as presented in Table 5.7-B:

Table 5.7-B

Nonconductive Polymer Overlay Components
O'Brien UC (Left)

COMPONENTS	QUANTITY
"Lonestar" Monterey B11 Sand	45.3 kg (100 lbs)
Pea Gravel, B39	45.3 kg (100 lbs)
Polyester Styrene Resin	9.1 kg (20 lbs)
MEKP Catalyst:	
Lane #1 (or, 1% by vol. of resin)	0.06 kg (2 oz)*
Lane #2 (or, 1/2% by vol. of resin)	0.03 kg (1 oz)*

* This was adjusted to compensate for the effect of differing summer temperatures during placement.

C. Installation Testing

Short circuit testing of the system, between the conductive primer coat and the deck reinforcing steel mat, was conducted. Previous laboratory testing had shown that the conductive primer used would not become sufficiently electrically conductive to detect a short circuit until it had cured for approximately 30 minutes. After this curing period, the short circuit testing was conducted on the bridge deck.

The short circuit test was performed similarly to the procedure used during the metallizing process (Section 5.5). A high impedance voltmeter (set on a low voltage DC scale) was connected between the reinforcing steel mat and the conductive primer coat. If no short circuit existed, (after the 30 minute cure period) the voltmeter displayed an open circuit potential. If a metallic (or conductive) path were encountered, the display would read "zero", indicating electrical continuity. During this testing, no short circuits were found.

D. Summary of System Components

The components of the Conductive Polymer CP system are given in Table 5.7-A.

Table 5.7-C

Conductive Polymer CP System Components
O'Brien UC (Left)

COMPONENT	DESCRIPTION	INSTALLATION
CP System	Four independent zones separated by 0.6 m (2 ft) wide nonconductive areas. Total anode area = 377.1 m^2 (4058.8 ft^2).	Installed: Summer 1988 Energized: November 1988
Conductive Primer	Prime coat composed of three parts polyester resin plus two parts graphite flake (by weight). resistivity < 1 ohm-cm; approx. thickness = 0.76 mm (0.03 in).	Applied to deck to ensure adequate bond between the distribution anode and the bridge deck (non-conductive primer mix used for clear areas between CP zones).
Primary Anode	Wire mesh, 8 gauge, 152 mm x 152 mm (6 in x 6 in) welded-wire fabric mat.	Attached to bridge deck with plastic cleats spaced approx. 0.6 m (2 ft) apart.
Current Distributor Bar (Bus Bar)	#10M (#3) steel reinforcing bar.	Wire-tied to primary anode wire mesh along shoulder to transfer CP current from rectifier lead to primary anode.
Distribution Anode	Conductive polymer anode composition: mineral aggregate, coke breeze, and fluid petroleum coke breeze. Average applied thickness = 43.43 mm (1.71 in). Resistivity <2.0 Ohm-cm.	Applied to four zones on bridge deck surface. Non-conductive polymer mix, at same thickness, was placed in clear areas between zones.
Overlay	None required. Polyester mixture sufficiently strong to withstand traffic wear.	
Rectifiers	Constant voltage, 20 volts DC, 5 amperes capacity.	System wired to existing rectifiers. Four rectifiers were used, wired independently.
Rebar Ground Connections	Two independent #8 gauge wire leads.	CADWELDED to rebar mat at two places on opposite ends of structure.

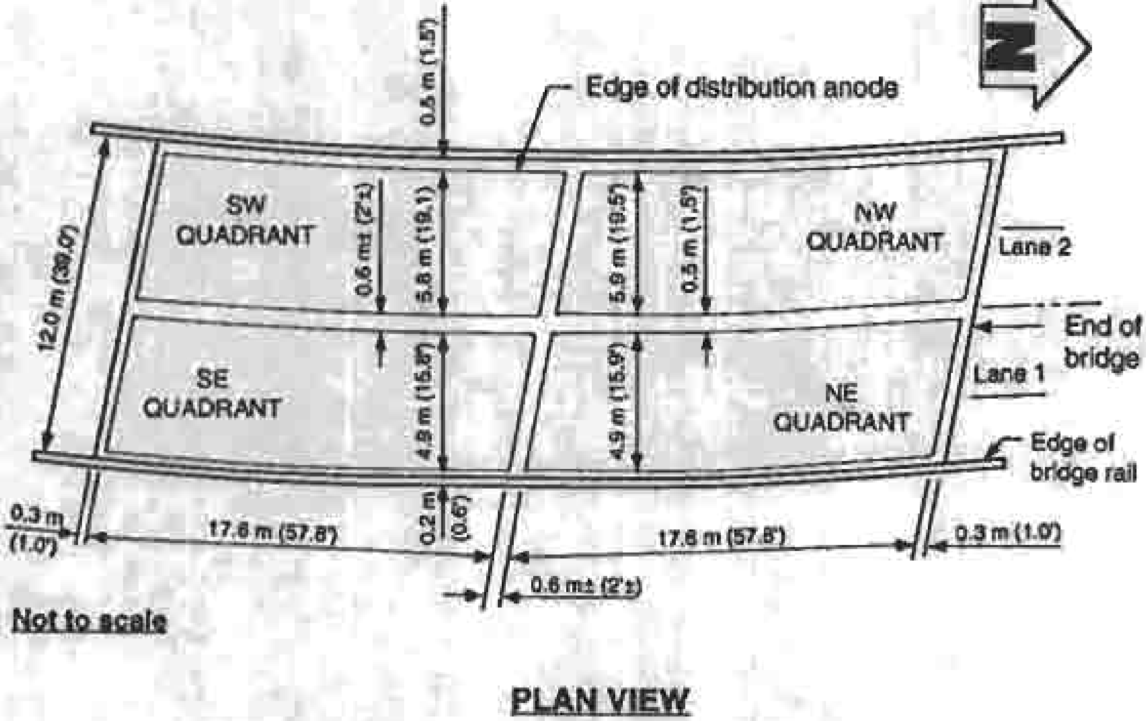


FIGURE 5.7-A Location and Dimensions of Distribution Anodes for Conductive Polymer CP System (4 Quadrants), O'Brien UC (Left)

FIGURE 5.7-B Wire Mesh Primary Anode Attached to Deck with Plastic Anchors, Conductive Polymer CP System, O'Brien UC (Left)

FIGURE 5.7-C Plastic Spacers Used on Wire Mesh Primary Anode, Conductive Polymer CP System, O'Brien UC (Left)

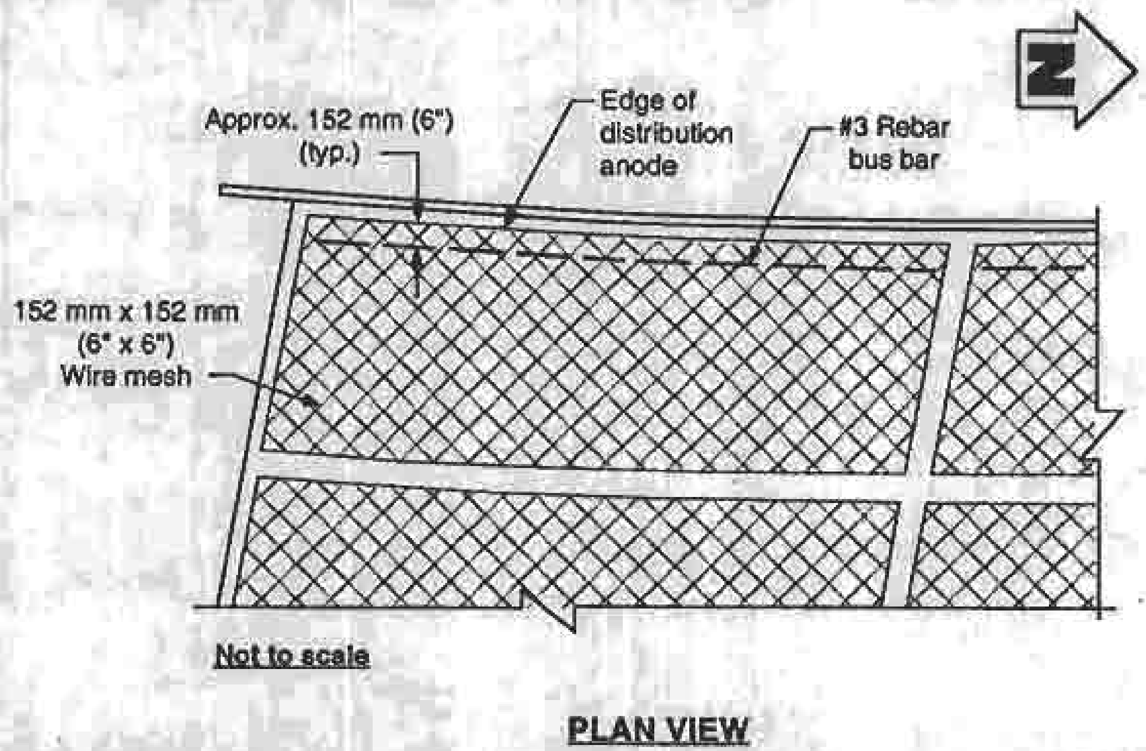


FIGURE 5.7-D Location of CP Current Distributor Bus Bar, O'Brien UC (Left), Plan View

FIGURE 5.7-E #10M Reinforcing Steel Bus Bar, Conductive Polymer CP System, O'Brien UC (Left)

6.0 CP DESIGN AND EVALUATION CRITERIA

6.1 Design Criteria

The delivery of CP current to the bridge deck reinforcing steel is influenced by the electrical resistance of the concrete and the continuity of the reinforcing steel in the deck. Consequently, for this study, the surface area of reinforcing steel used for current density calculations is the steel mat closest to the current delivery anodes (the top reinforcing steel mat), directly beneath the distribution anode.

The ratio of the surface area of the reinforcing steel in the top rebar mat versus the deck concrete surface area is approximately 0.5 to 1.

Table 6.0-A gives the surface areas of the distribution anodes (based on field measurements), the top reinforcing steel mat of each CP zone, as well as the assumed exposed surface areas of the epoxy coated steel overlay mats for the Raychem and Eltech CP systems.

Table 6.0-A

Distribution Anodes and Top Mat Reinforcing Steel Surface Areas

CP ANODE	CP ZONE	CP ANODE AREA m^2 (ft^2)	REINFORCING STEEL AREA m^2 (ft^2)
Coke Breeze	1	96.5 (1038.6)	48.2 (519.2)
	2	113.6 (1222.8)	56.8 (611.4)
	Total	210.1 (2261.3)	105.0 (1130.6)
Metallized Zinc	1	96.2 (1035.6)	48.1 (517.8)
	2	95.4 (1026.5)	47.7 (513.3)
	Total	191.6 (2062.1)	95.8 (1031.1)
Raychem "Ferex 100"	1	96.4 (1037.7)	48.2 (518.9)
	2	110.1 (1185.3)	55.1 (592.6)
	Total	206.5 (2223)	103.3 (1111.5)
Raychem "Ferex 100" Overlay	1	96.4 (1037.7)	0.38 (4.1)* 18.8 (202.8)**
	2	110.1 (1185.3)	0.44 (4.7)* 21.6 (232.7)**
	Total	206.5 (2223)	0.82 (8.8)* 40.5 (435.5)**
Eltech "Elgard 210"	1	88.6 (953.4)	44.3 (476.7)
	2	109.9 (1182.6)	54.9 (591.3)
	Total	198.4 (2136)	99.2 (1068)
Eltech "Elgard 210" Overlay	1	88.6 (953.4)	0.35 (3.8)* 17.5 (188.1)**
	2	109.9 (1182.6)	0.44 (4.7)* 21.5 (231.6)**
	Total	198.4 (2136)	0.79 (8.5)* 39.0 (419.7)**
Conductive Polymer	NW	104.7 (1127.1)	52.4 (563.6)
	SW	102.6 (1104.0)	51.3 (552.0)
	NE	85.2 (916.6)	42.6 (458.3)
	SE	84.6 (911.1)	42.3 (455.6)
	Total	377.1 (4058.8)	188.5 (2029.4)

* Assumed bare steel area of epoxy coated reinforcing steel.

** Total surface area of epoxy coated reinforcing steel in CP zone.

Part of the design of a CP system is the selection of an appropriate current density required for adequate protection. Although an initial design maximum current density of 21.5 mA/m^2 (2 mA/ft^2) of steel area, which is equivalent to 10.8 mA/m^2 (1 mA/ft^2) of concrete surface, was selected for this study, start-up test results indicated that the 100 mV depolarization criteria could be achieved with far less current density. From this point on, the current density delivered was dictated by maintaining a depolarization value of or near 100 mV.

6.2 Evaluation Criteria

CATHODIC PROTECTION CRITERIA: A key indicator of the effectiveness of CP is the measurement of the electrical potential of the reinforcing steel in the structure. Typical values measured on steel in concrete range from -0.100 to -0.600 volts versus $Cu/CuSO_4$ reference electrodes. Values more negative than -0.350 volts (vs. $Cu/CuSO_4$) generally indicate that active corrosion is occurring (ASTM Designation C-876)[7]. In theory, due to the electrochemical nature of steel in concrete when CP is applied, as the potential becomes more negative, a point is reached where corrosion is mitigated. In general, as more CP current is applied, the shift becomes more negative. The amount of this potential shift is an indication of the degree of corrosion protection being achieved.

The "working" criterion used in this study for reinforced concrete was the achievement of a 0.100 volt polarization shift over a 4-hour period in a more negative direction due to the application of CP current[5].

POLARIZATION DECAY SURVEYS: Since it is difficult to measure potential while the CP current is actually flowing, the rectifier is turned off and measurements are taken immediately thereafter. This technique is commonly known as taking "instant-off" potential measurements.

If the CP current remains off, the reinforcing steel will return to its "natural" or "native" potential by shifting in a positive direction. This return, or "decay" as it is called, may take a few hours or several days depending on many factors. In this study, the polarization shift was determined from the polarization decay established during the four hour instant-off procedure.

Fourteen half-cell test ports were placed at measured locations within each CP system. All fourteen half-cell ports were used for testing during initial readings and evaluation of the CP systems, but only the seven half-cell ports located in the shoulder area of each CP zone were used during polarization decay testing after the structure was re-opened to traffic.

Figure 6.0-A shows the locations of all fourteen half-cell ports in each CP system, and identifies those seven half-cell ports in the roadway shoulder area of each system that were used during the 6 years of CP evaluation.

The half-cell ports for Upper Salt Creek Lane 2 were formed before placing the concrete overlay. All other half-cell ports were cored and backfilled after the overlays had been placed. Appendix 10.8 presents the procedures used for installing these half-cell ports.

A number of instant-off and polarization decay surveys were conducted during the operational period for the CP systems on these structures. These surveys were conducted in such a way that multiple locations across the deck were monitored simultaneously during the instant-off period and these same locations were monitored continuously throughout the polarization decay period.

The polarization decay data presented in this report were recorded using a multi-channel high-speed data acquisition recorder to capture the transient voltages measured.

Section 7.3 presents the polarization decay results of the instant-off surveys conducted on the bridge deck as well as the average current density for each CP system.

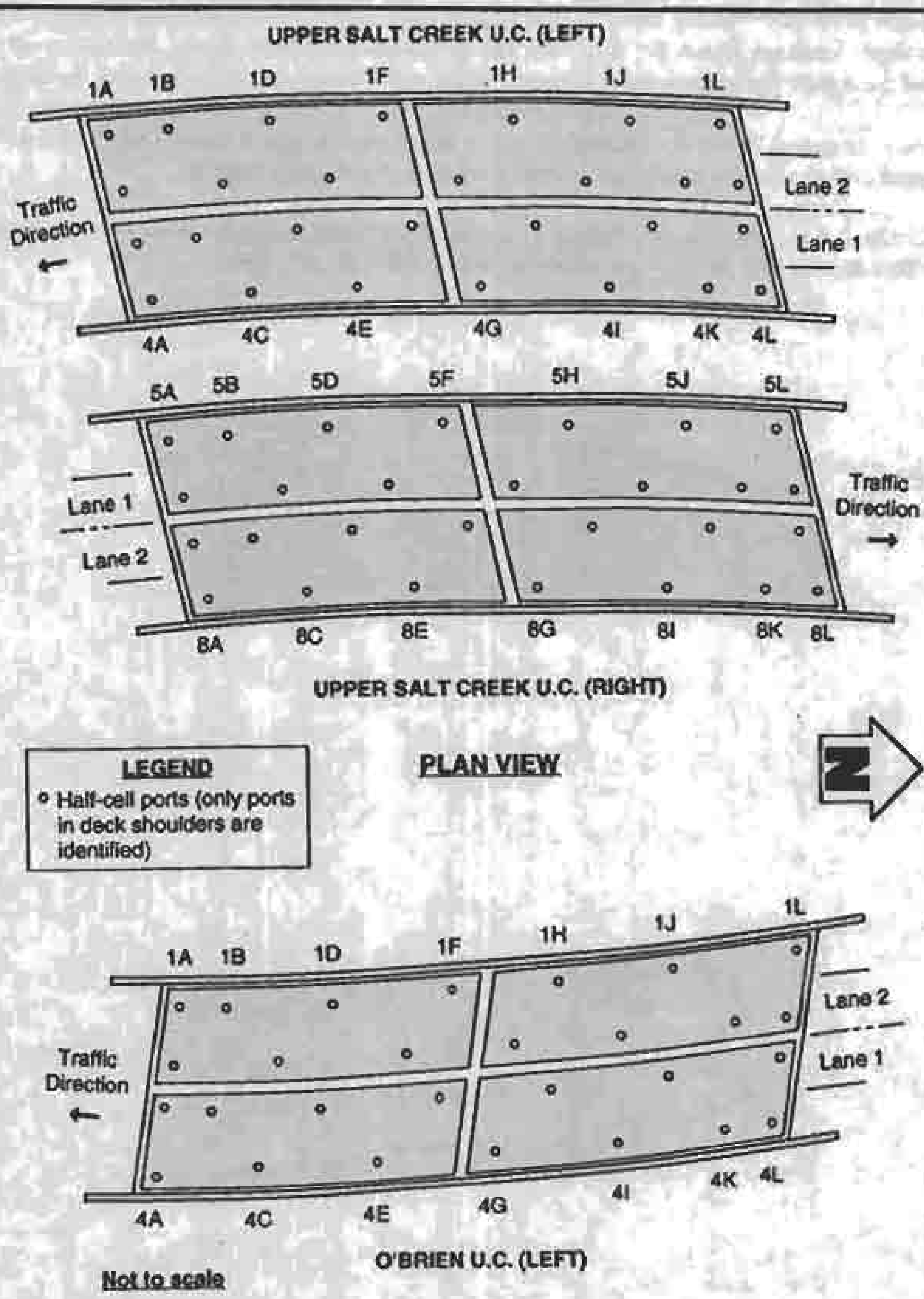


FIGURE 6.0-A Half-Cell Port Locations and Identification on each Structure

7.0 RESULTS

7.1 Preliminary Site Tests.

The results of all testing conducted as described in Section 5.2; Preliminary Site Repair and Testing, are presented as follows:

DECK DELAMINATIONS: Figure 7.1-A is a plan view of each bridge deck showing the delaminated areas detected and repaired during this study prior to placing the CP systems. The square footage of the delaminated areas for the bridge decks are presented in Table 7.1-A.

CHLORIDE CONCENTRATION TESTS: Table 7.1-B presents the results of chloride concentration testing of the concrete cores removed from each bridge deck. The results of the bridge deck concrete are recorded versus the depth from the top surface of the deck.

CONCRETE COVER SURVEYS: Table 7.1-C presents the results of the surveys conducted during the 1975 CP installations, reported in 1981[2].

The deck surface of Upper Salt Creek UC (Right) was milled an additional 6.35 mm (1/4 in) during this contract to prepare the deck for the low slump concrete overlay.

HALF-CELL CORROSION POTENTIAL SURVEYS: The results of the data gathered from the May 1987 half-cell potential surveys of Upper Salt Creek UC (Left) and O'Brien UC (Left), and the May/June 1988 survey of Upper Salt Creek UC (Right) have been plotted as topographic maps of equi-potential lines in Figure 7.1-B.

Additional corrosion potential readings were taken through each reference cell access port after the CP systems were installed, prior to energizing. These data are presented in Section 7.3, Figures 7.3-F through 7.3-M, along with the polarization decay test results taken throughout this study. Refer to Figure 6.0-A for the location of each half-cell access port used for these measurements.

SHORT CIRCUIT TESTS: The short circuit testing was performed as described in Section 5.2. Many exposed metal contacts (locations of possible short circuits) were found in each deck during the survey periods.

Numerous exposed rebar tie wires were located on the Upper Salt Creek UC (Right) structure during the deck survey. It is possible that these wires were exposed due to the additional depth of grinding performed on this deck in preparation for placing the concrete overlay.

Table 7.1-A

Existing Deck Delaminated Areas
Prior To CP Application

BRIDGE DECK	LANE 1		LANE 2		TOTAL
	m^2 (ft^2)	(%)	m^2 (ft^2)	(%)	(%)
UPPER SALT CREEK UC (LT)	25.7 (276.8)	5.8	39.1 (420.4)	8.8	14.5
UPPER SALT CREEK UC (RT)	10.7 (114.8)	2.4	10.4 (112.4)	2.3	4.7
O'BRIEN UC (LT)	8.9 (96.1)	2.1	6.4 (69.1)	1.5	3.5

* Percent shown is relative to total deck surface

Table 7.1-B

Chloride Concentration of Bridge Deck Concrete
kg Chloride/m^3 (lb Chloride/yd^3)

DEPTH mm (in)	AVERAGE	MEDIAN	RANGE	NO. OF SAMPLES TESTED
UPPER SALT CREEK UC, (LEFT)				
0 - 25 (0-1)	0.82 (1.38)	0.74 (1.25)	0.53-1.30 (0.90-2.20)	6
25 - 50 (1-2)	0.47 (0.80)	0.39 (0.65)	0.36-0.71 (0.60-1.20)	6
50 - 75 (2-3)	0.30 (0.50)	0.30 (0.50)	0.18-0.42 (0.30-0.70)	5
75 - 100 (3-4)	0.21 (0.36)	0.24 (0.40)	0.18-0.24 (0.30-0.40)	3
100 - 125 (4-5)	0.12 (0.20)	--	-- --	1
UPPER SALT CREEK UC, (RIGHT)				
0 - 25 (0-1)	0.52 (0.87)	0.44 (0.75)	0.06-0.89 (0.10-1.50)	8
25 - 50 (1-2)	0.31 (0.53)	0.33 (0.55)	0.18-0.53 (0.30-0.90)	8
50 - 75 (2-3)	0.21 (0.35)	0.18 (0.30)	0.06-0.42 (0.10-0.70)	8
75 - 100 (3-4)	0.15 (0.25)	0.15 (0.25)	0.06-0.24 (0.10-0.40)	4
100 - 125 (4-5)	0.06 (0.10)	--	-- --	1
O'BRIEN UC, (LEFT)				
0 - 25 (0-1)	0.60 (1.02)	0.53 (0.90)	0.36-1.01 (0.60-1.70)	4
25 - 50 (1-2)	0.31 (0.52)	0.33 (0.55)	0.18-0.42 (0.30-0.70)	4
50 - 75 (2-3)	0.27 (0.46)	0.30 (0.50)	0.24-0.30 (0.40-0.50)	4
75 - 100 (3-4)	0.30 (0.50)	--	-- --	2
100 - 125 (4-5)	0.24 (0.40)	--	-- --	1

Table 7.1-C

Concrete Cover Over the Top Mat of Deck Reinforcing Steel, 1975 Survey

(Recorded as % of Total Deck Surface Area)

BRIDGE DECK	CONCRETE COVER RANGE mm (in)		
	<25.4 (< 1.0)	25.4 to 50.8 (1.0 to 2.0)	>50.8 (> 2.0)
UPPER SALT CREEK UC (LEFT)	15.3	71.6	13.1
UPPER SALT CREEK UC (RIGHT)	5.1	90.6	4.3
O'BRIEN UC (LEFT)	0	95.5	4.5

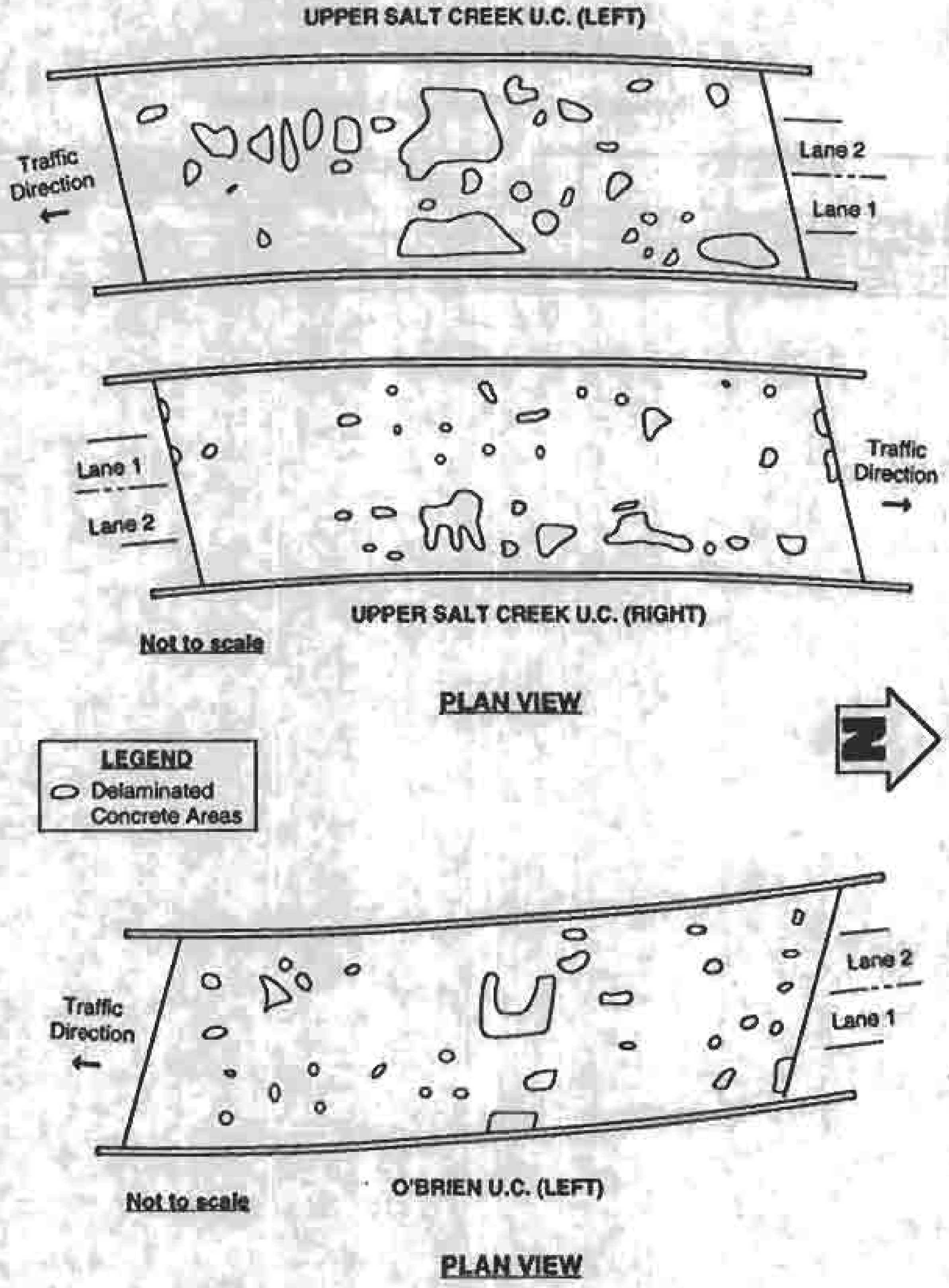


FIGURE 7.1-A Bridge Deck Delaminated Areas

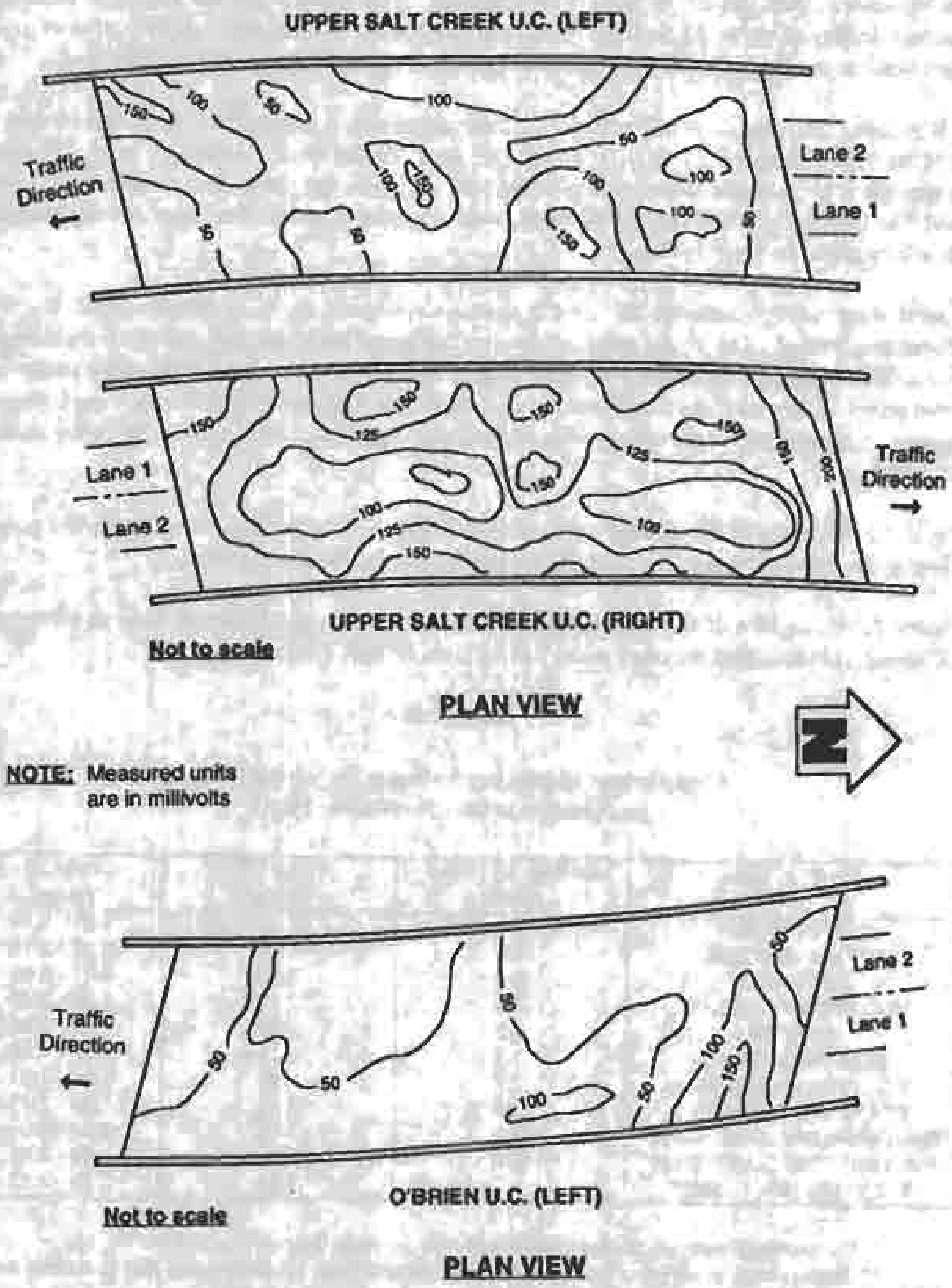


FIGURE 7.1-B Bridge Deck Corrosion Potentials (Negative Values vs $Cu/CuSO_4$ Half-Cell)

7.2 Cathodic Protection Operational Parameters

In November 1988, all CP systems were activated. The start-up criteria used was to achieve a current density of either 21.5 mA/m^2 (2 mA/ft^2) of steel or a minimum depolarization of 100 mV measured over a 5 to 15 minute period after the "start-up test" instant-off was initiated.

All systems exceeded the 100 mV decay start-up criteria at current densities that ranged from 1.61 to 7.64 mA/m^2 (0.15 to 0.71 mA/ft^2) of steel for the deck reinforcing steel CP systems. Although not evaluated during the start-up test, rectifiers for the overlay reinforcing steel for both the Raychem and Eltech CP systems, were adjusted to reflect the same driving voltages as their respective deck CP systems.

The driving voltage settings for all CP systems remained unchanged throughout the 6 year monitoring period. The actual recorded driving voltage at each rectifier varied during this period due to fluctuations in electrical resistance within each CP circuit. Since the analog meter on the front panel of the rectifiers are inherently inaccurate for research testing, the driving voltage and current measurements were taken using an external digital multimeter throughout the course of this study.

Table 7.2-A compares the driving voltage, while Figures 7.2-A through 7.2-E provide a graphical view of the driving voltage for each CP system for the duration of the study.

Figure 7.2-F is a plot of the monthly precipitation versus time, which was used to represent the CP sites. This data was recorded at the Shasta Dam NOAA Station.

Table 7.2-A

Comparison of Driving Voltages for Each CP System (November 1988 – November 1994)

CP SYSTEMS	INITIAL SETTING (Volts)	AVERAGE (Volts)	RANGE (Volts)
COKE BREEZE	2.5	2.34	1.91 - 3.31
METALLIZED ZINC	1.5	1.45	0.21 - 2.10
RAYCHEM	2.4	2.42	1.81 - 3.90
RAYCHEM OVERLAY	2.3	2.20	1.80 - 2.75
ELTECH	1.2	1.25	1.06 - 1.80
ELTECH OVERLAY	1.3	1.21	1.07 - 1.60
POLYMER (NE QUAD.)	2.7	2.89	1.82 - 3.62
POLYMER (SE QUAD.)	2.0	1.95	1.20 - 2.73
POLYMER (NW QUAD. Only)*	3.0	1.32	0.50 - 3.01
POLYMER (SW QUAD. Only)*	2.7	2.37	1.50 - 2.79
POLYMER (NW & SW)**	-	2.75	2.19 - 3.57

* Data reflects analysis of measurements taken on these systems up to April 30, 1992.

** Data reflects analysis of measurements taken after April 30, 1992 when NW Quadrant was connected to SW Quadrant rectifier.

Figure 7.2-A Variations in Driving Voltage vs Time
Coke Breeze and Metallized Zinc CP Systems

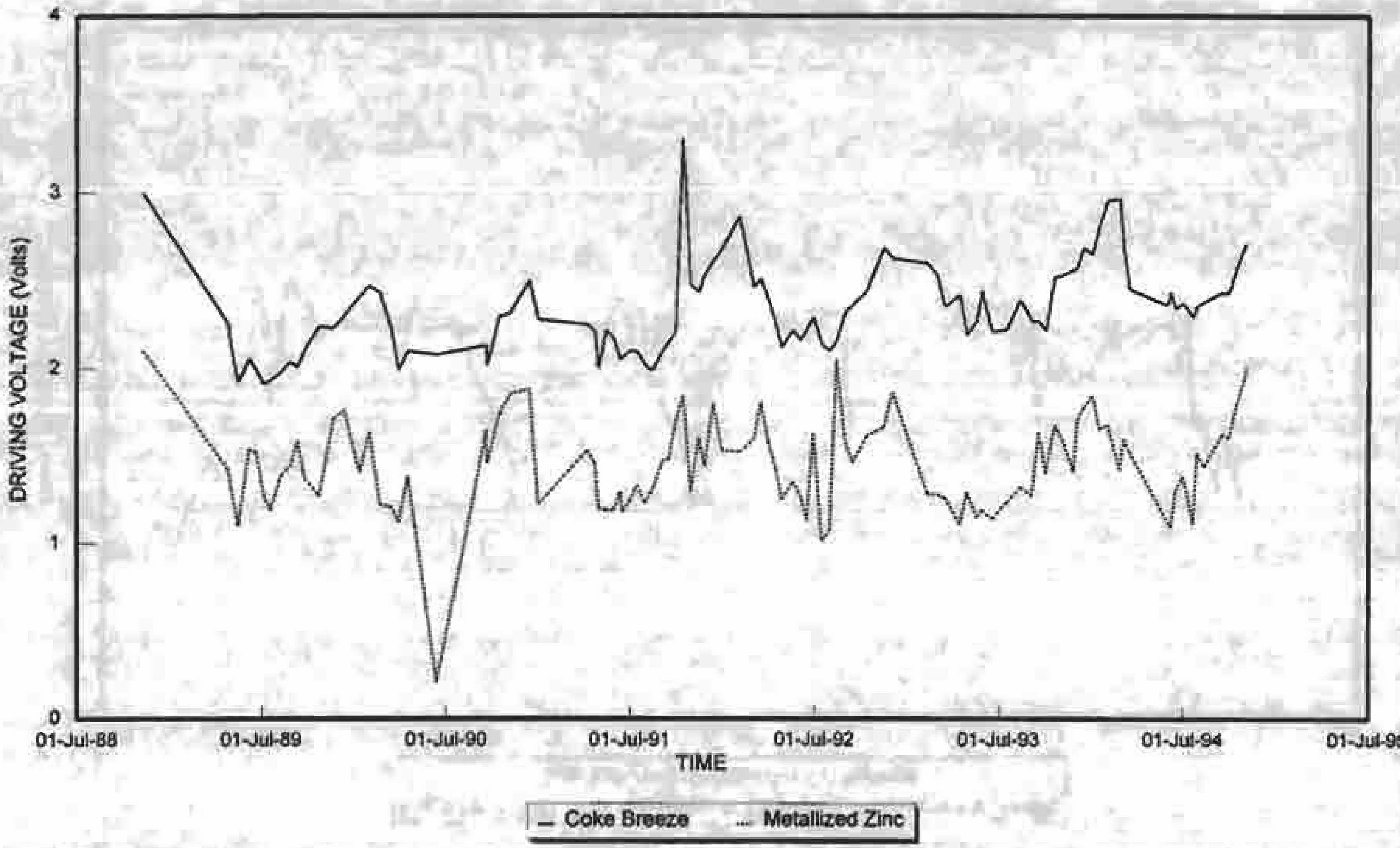
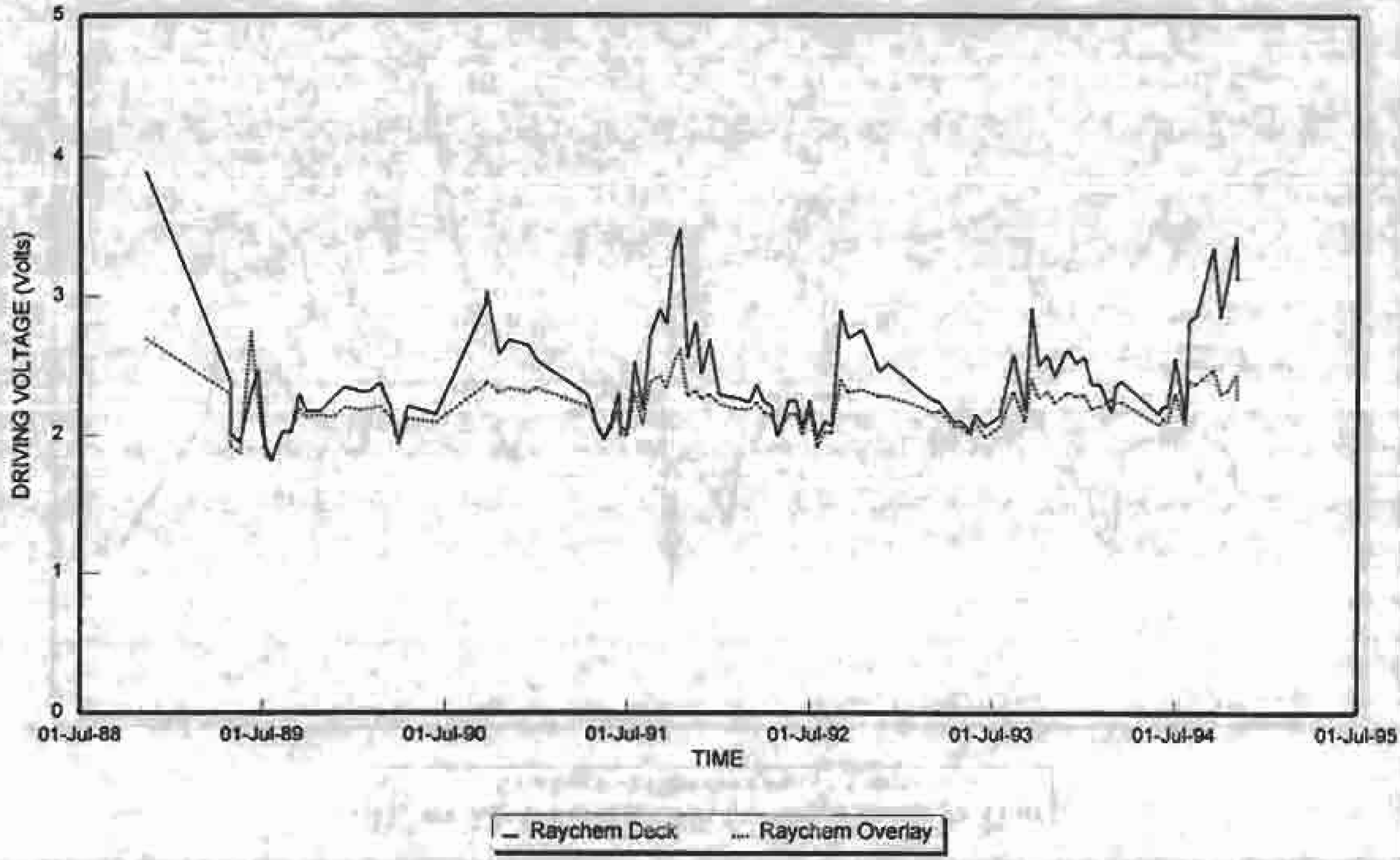


Figure 7.2-B Variations in Driving Voltage vs Time
Raychem Deck and Overlay CP Systems



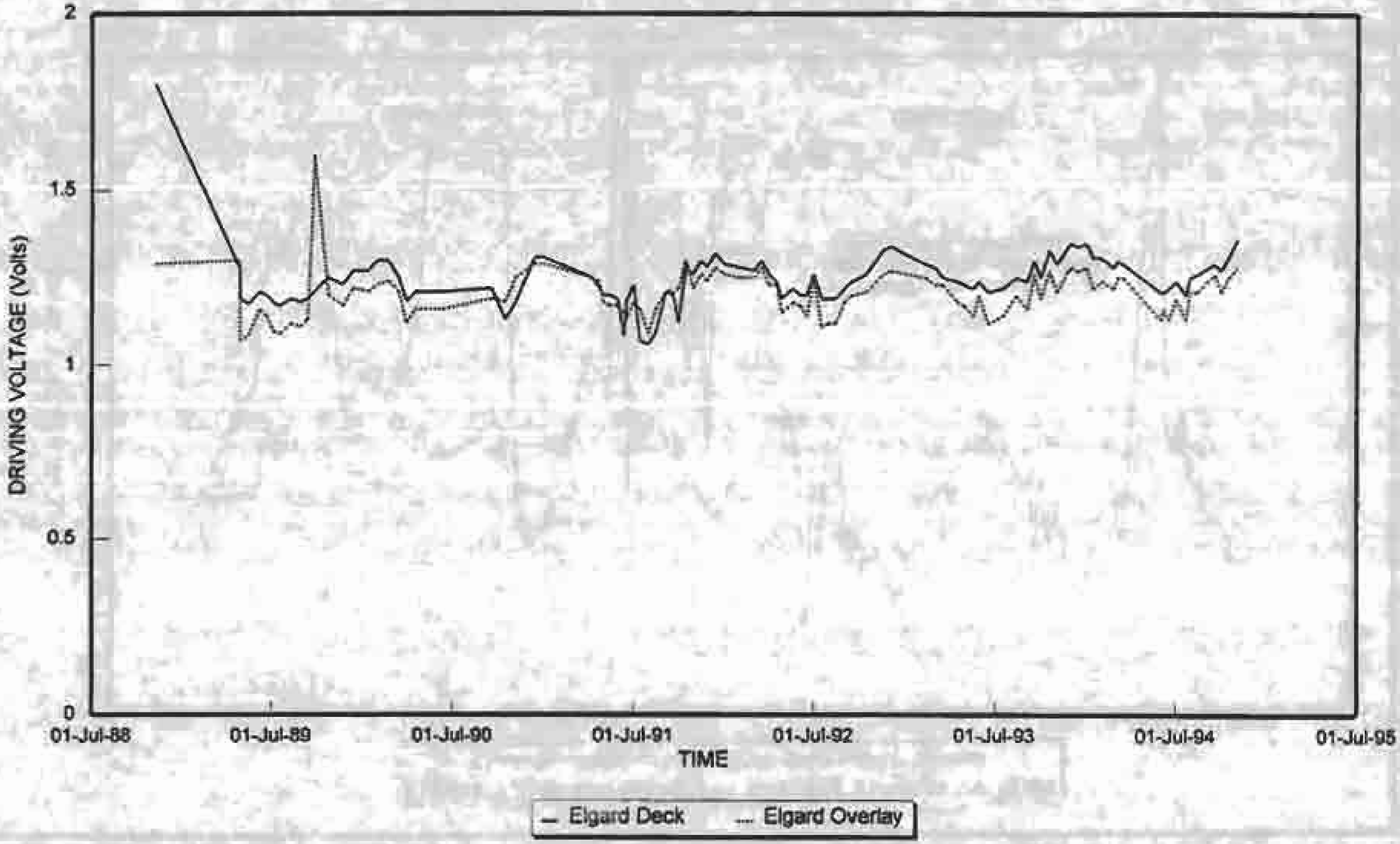


Figure 7.2-C Variations in Driving Voltage vs Time
Elgard Deck and Overlay CP Systems

Figure 7.2-D Variations in Driving Voltage vs Time

Conductive Polymer NW and SW Quadrant CP Systems

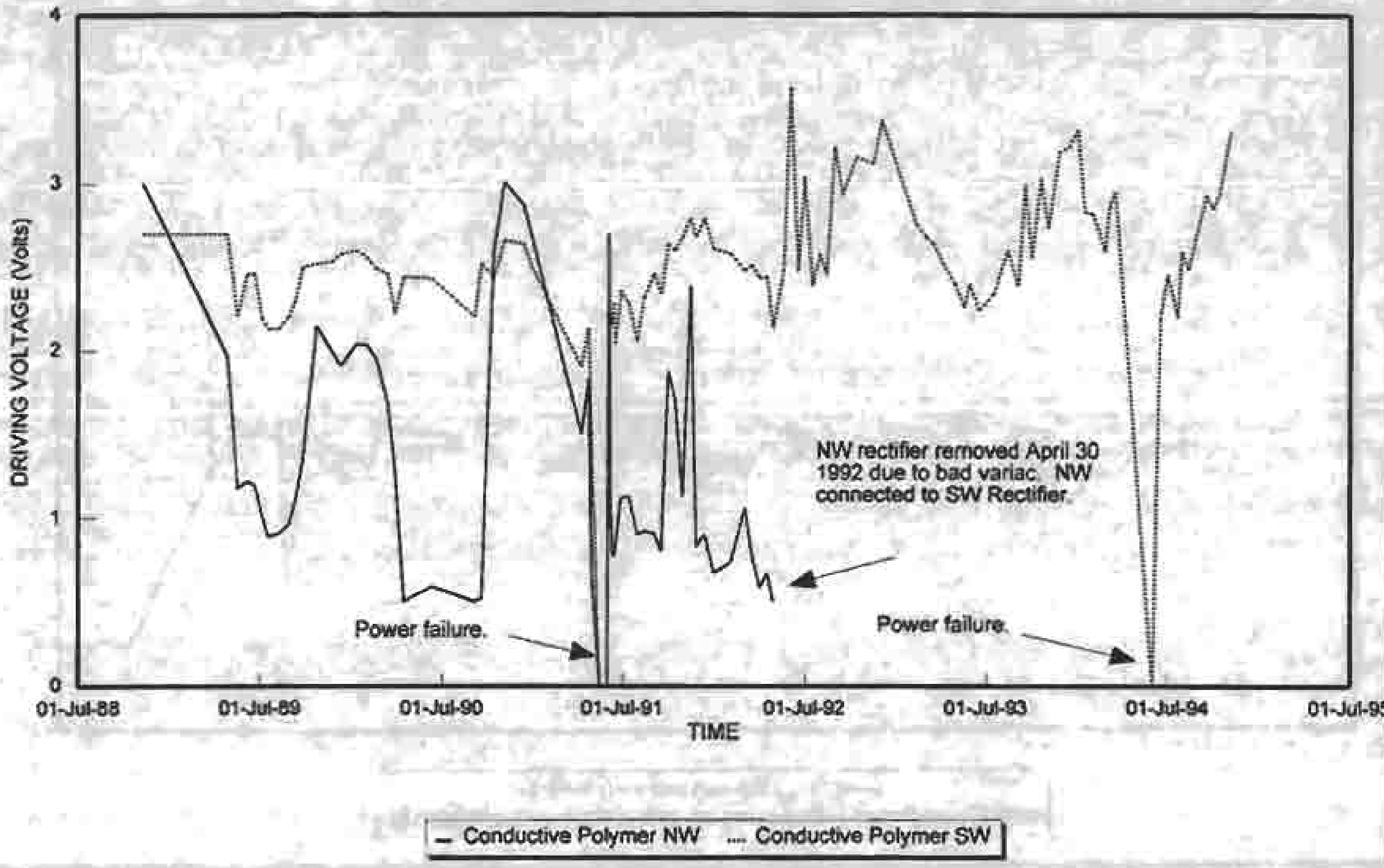


Figure 7.2-E Variations in Driving Voltage vs Time
Conductive Polymer NE and SE Quadrant CP Systems

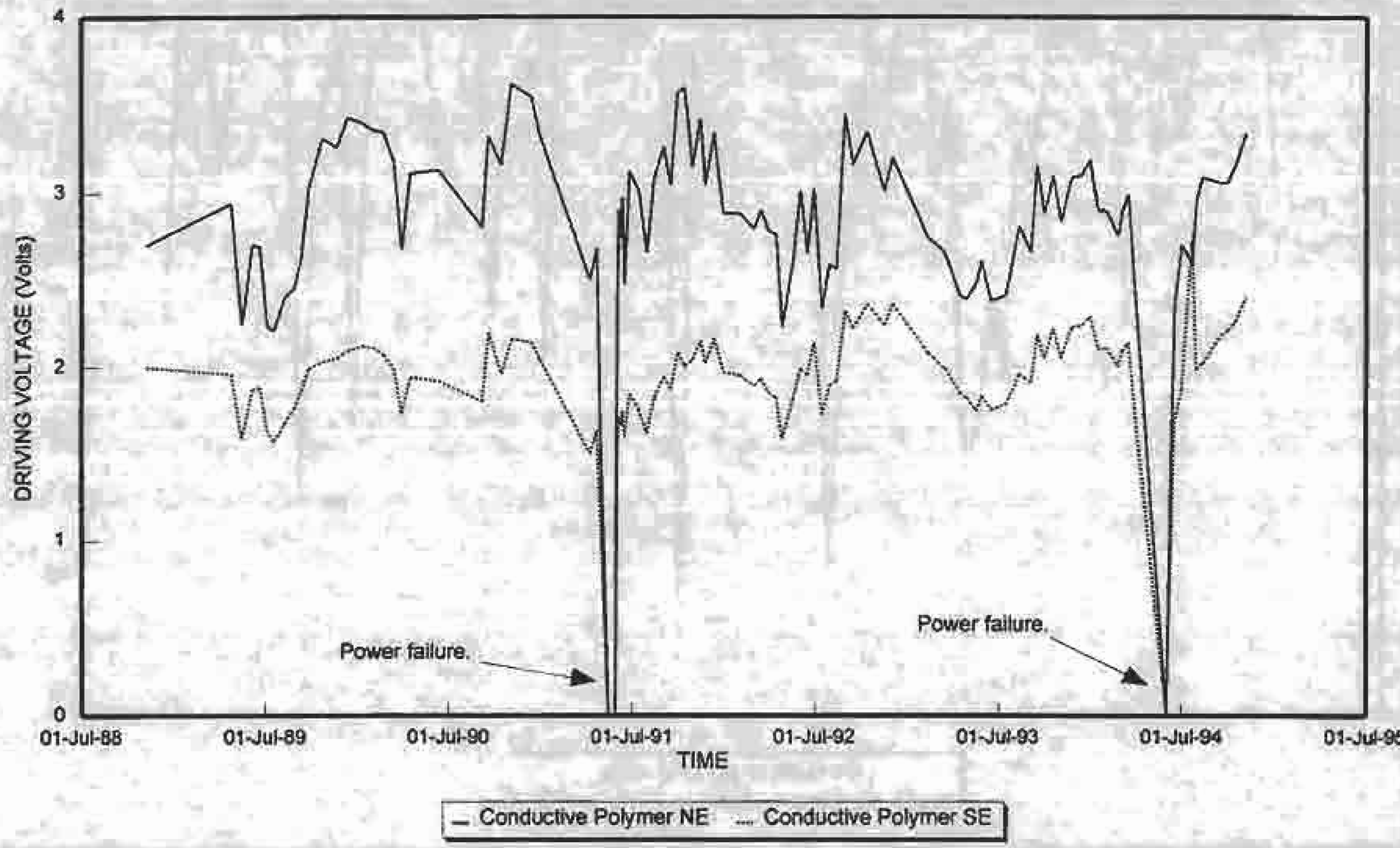
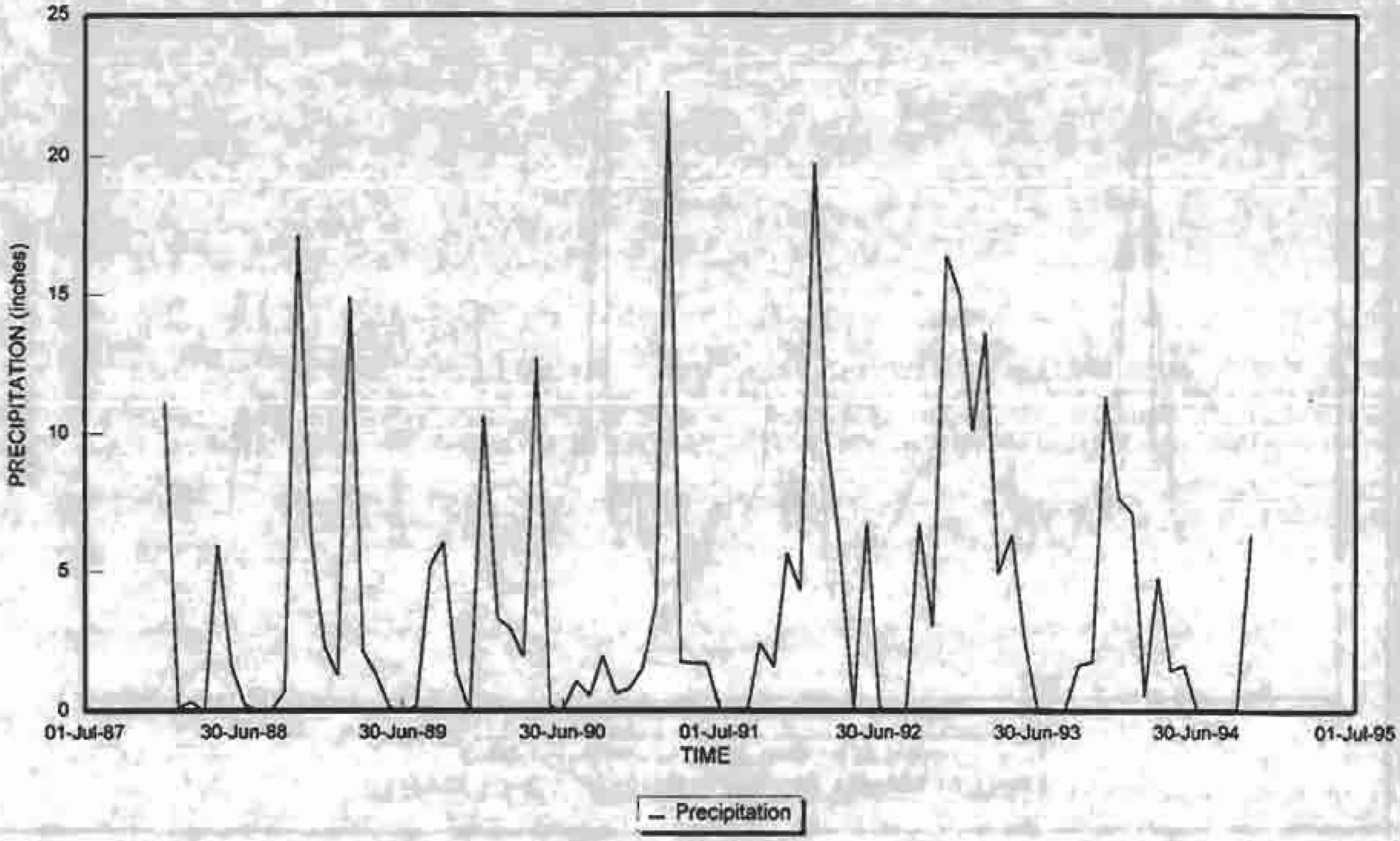


Figure 7.2-F Precipitation vs Time
"Recorded as Monthly Totals"



7.3 Cathodic Protection Effectiveness

CURRENT DELIVERED: Local differences within the concrete such as density, cracks, the degree of salt contamination, previous deck patching materials, and varying moisture content can create preferential paths for current flow. These differences can prevent the CP current from being uniformly distributed to the reinforcing steel in the deck.

Graphs showing cumulative current delivered over the 6 year monitoring period for the CP systems are presented in Figures 7.3-A through 7.3-E.

CURRENT DENSITY: The initial tests conducted during the start-up procedures indicated that the current densities of each CP system ranged from 1.61 to 7.64 mA/m^2 (0.15 to 0.71 mA/ft^2) of steel. During normal operation, the current densities measured throughout the 6 year monitoring period varied. Table 7.3-A gives a comparison of the average and range for the current density for each CP system.

POLARIZATION DECAY: The polarization decay results from 4 hour instant-off surveys of are presented in Table 7.3-B for each CP system. In addition, Figures 7.3-F through 7.3-M present polarization decay values for each CP system relative to corresponding reference cell locations on the bridge deck. These data are presented along with the results of the initial open circuit corrosion potential survey, taken from each reference cell port, conducted prior to energizing the CP systems.

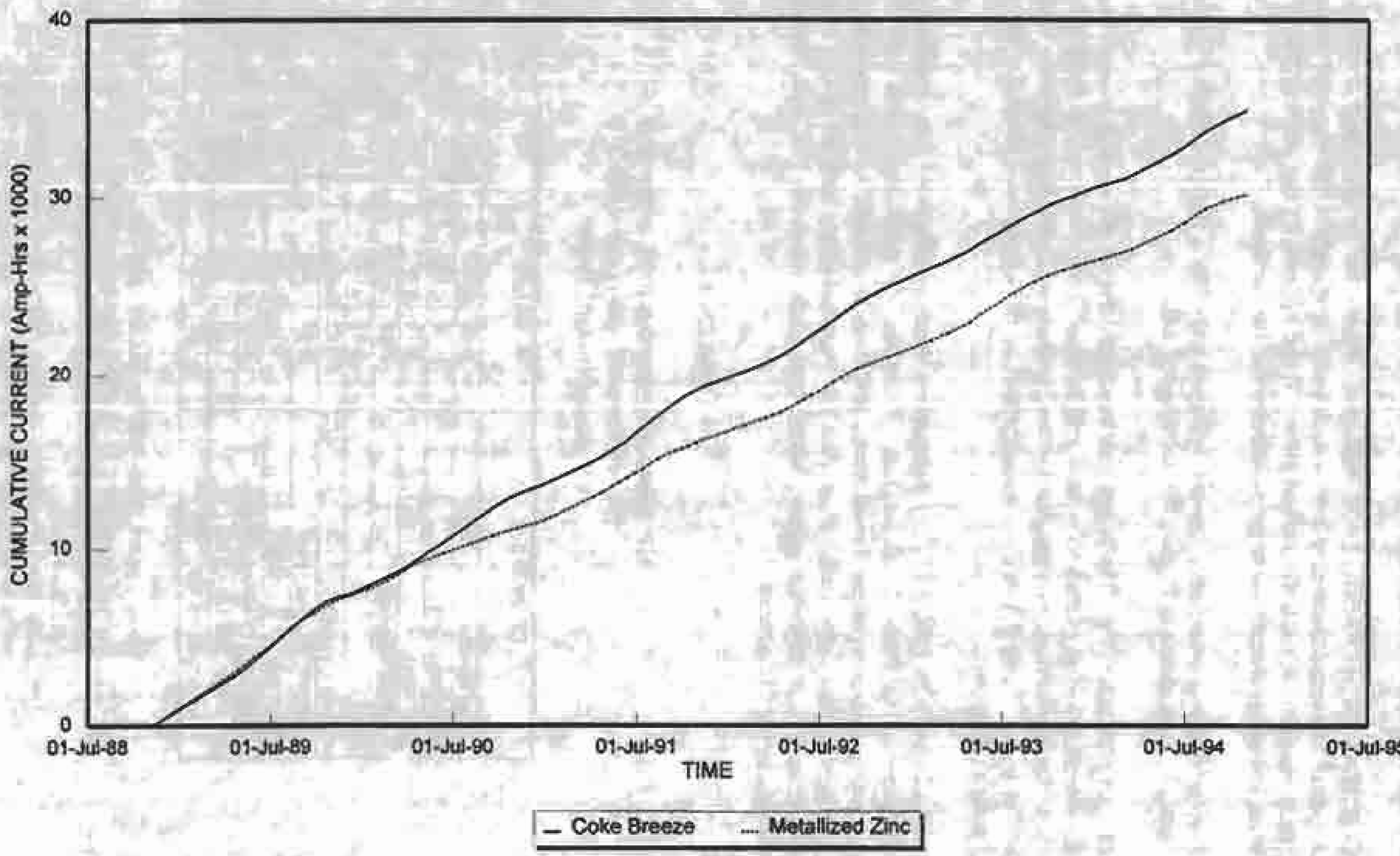
Table 7.3-A

CP System Current Density Comparison
(November 1988 - November 1994)
mA/m^2 (mA/ft^2) steel

CP SYSTEM	AVERAGE	RANGE
Coke Breeze	6.46 (0.60)	0.97 - 11.41 (0.09 - 1.06)
Metallized Zinc	6.03 (0.56)	3.12 - 11.52 (0.29 - 1.07)
Raychem	4.74 (0.44)	0.97 - 7.75 (0.09 - 0.72)
Raychem Overlay	7.86 (0.73)	0.43 - 27.23 (0.04 - 2.53)*
Eltech	6.46 (0.60)	3.01 - 8.07 (0.28 - 0.75)
Eltech Overlay	10.55 (0.98)	5.27 - 22.07 (0.49 - 2.05)**
Polymer, NE Quadrant	5.27 (0.49)	1.61 - 32.83 (0.15 - 3.05)
Polymer, SE Quadrant	3.55 (0.33)	0.97 - 30.68 (0.09 - 2.85)
Polymer, NW Quadrant Only ***	2.48 (0.23)	0.22 - 20.99 (0.02 - 1.95)
Polymer, SW Quadrant Only ***	3.01 (0.28)	0.53 - 11.73 (0.05 - 1.09)
Polymer, NW & SW ****	4.20 (0.39)	1.72 - 7.75 (0.16 - 0.72)

* Epoxy Coated Steel - Calculated bare steel area of 0.81 m^2 (8.76 ft^2).
** Epoxy Coated Steel - Calculated bare steel area of 0.78 m^2 (8.44 ft^2).
*** Data reflects analysis of measurements taken on these systems up to April 30, 1992.
**** Data reflects analysis of measurements taken after April 30, 1992 when NW Quadrant was connected to SW Quadrant rectifier.

Figure 7.3-A Cumulative Current Delivered vs Time
Coke Breeze and Metallized Zinc Deck CP Systems



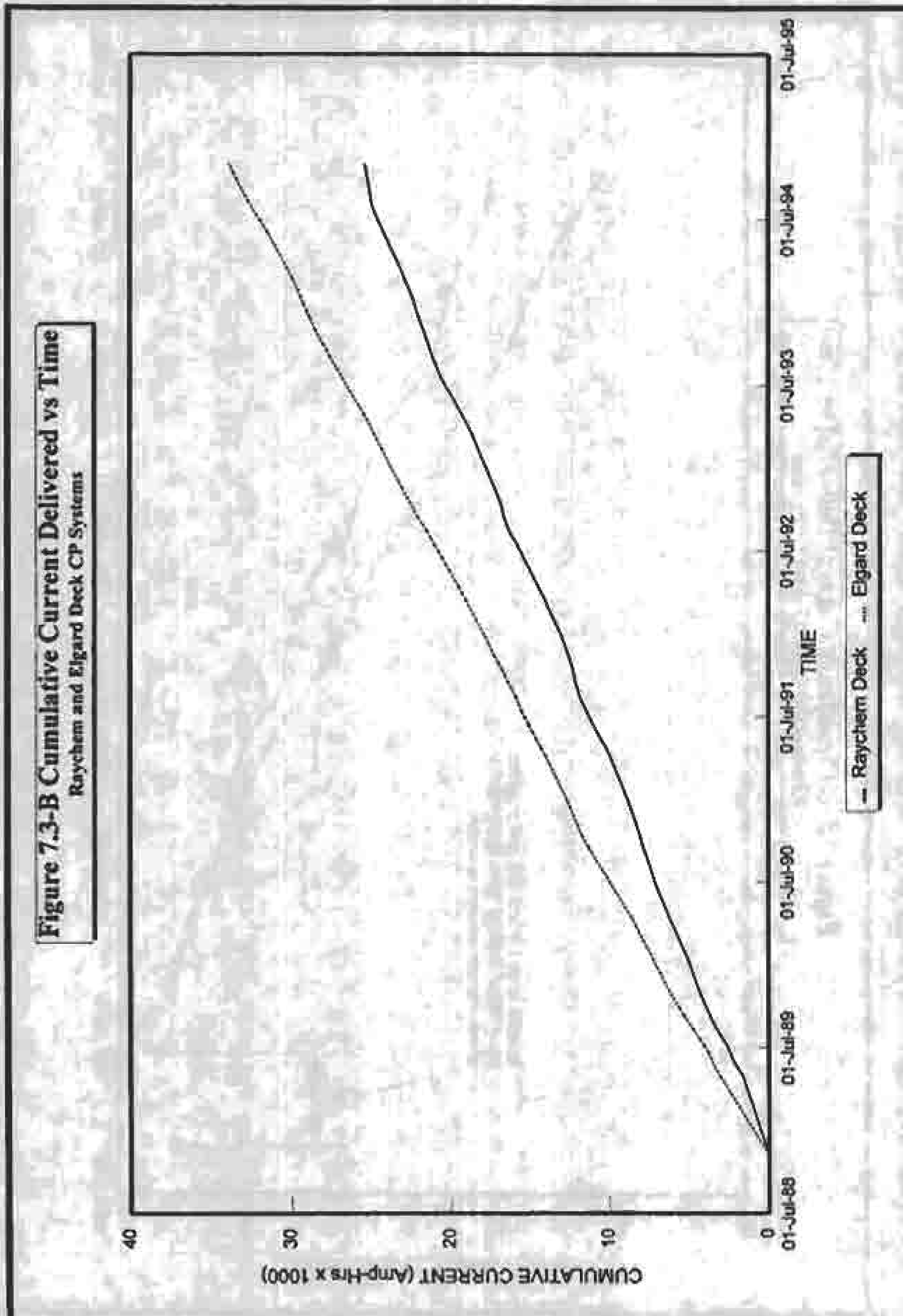
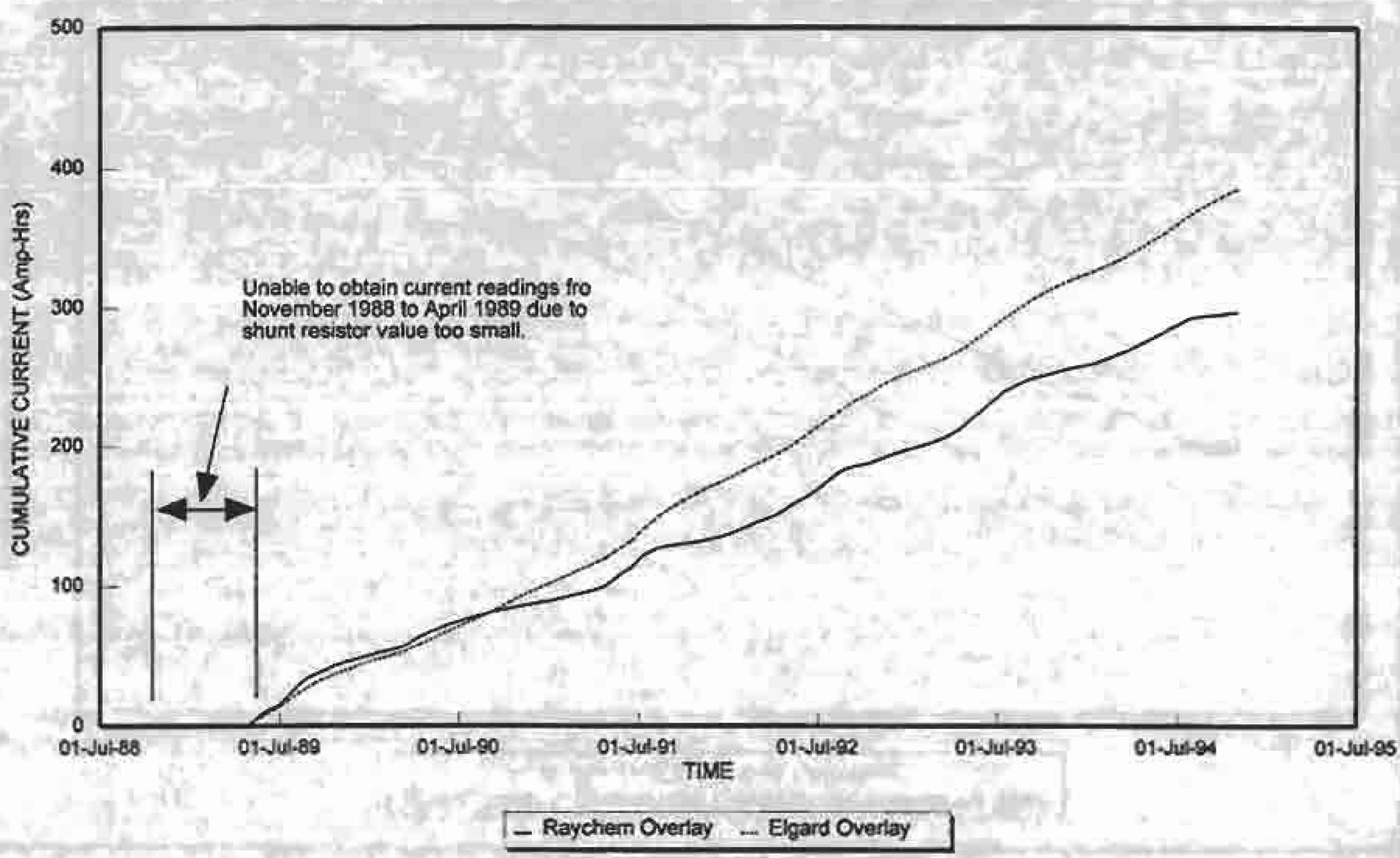


Figure 7.3-B Cumulative Current Delivered vs Time
Raychem and Elgard Deck CP Systems
CUMULATIVE CURRENT (Amp-Hrs x 1000)
0
10
20
30
40
01-Jul-88
01-Jul-89
01-Jul-90
01-Jul-91
01-Jul-92
01-Jul-93
01-Jul-94
01-Jul-95
TIME
Raychem Deck
Elgard Deck

Figure 7.3-C Cumulative Current Delivered vs Time
Raychem and Elgard Overlay CP Systems



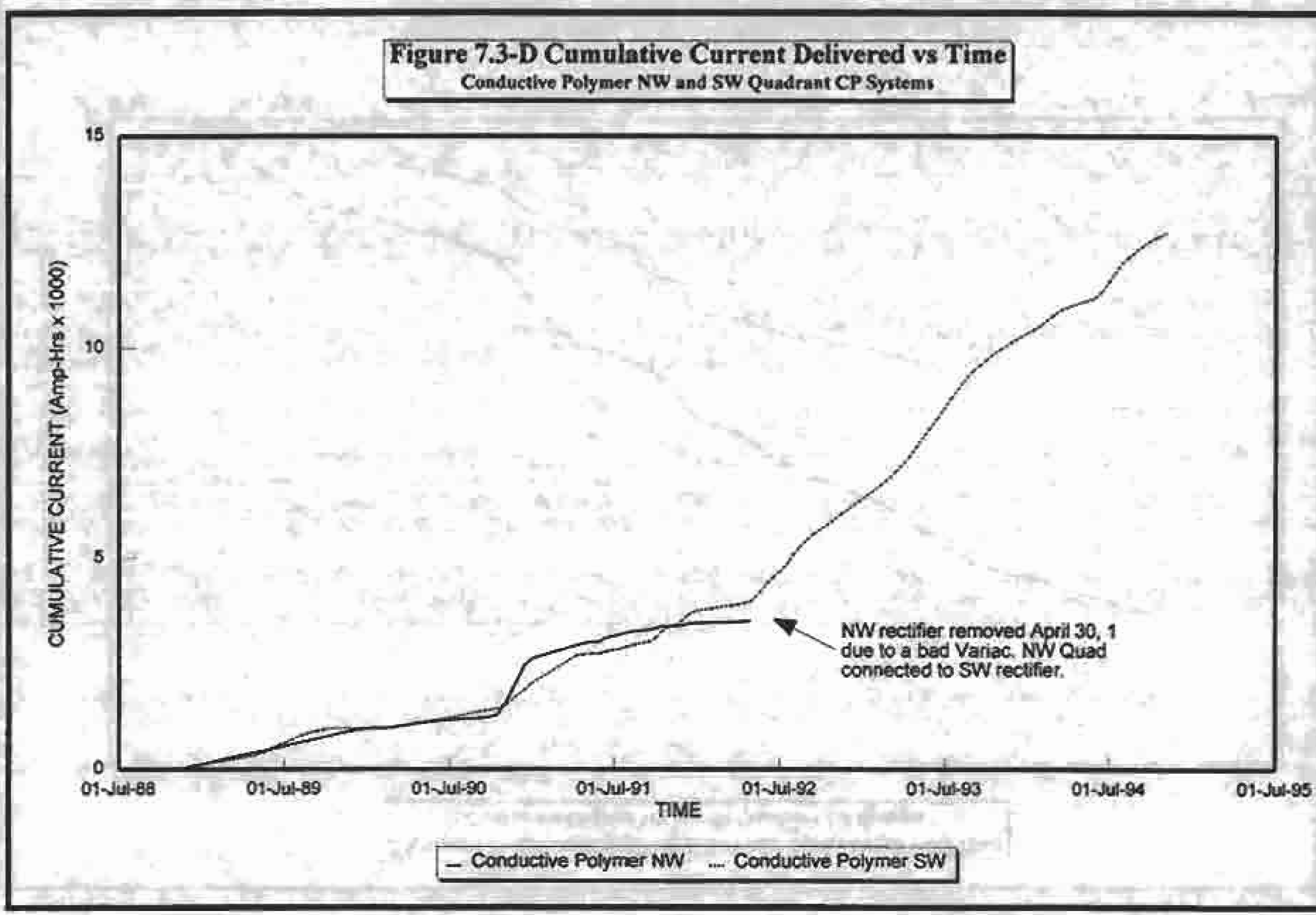


Figure 7.3-D Cumulative Current Delivered vs Time
Conductive Polymer NW and SW Quadrant CP Systems
CUMULATIVE CURRENT (Amp-Hrs x 1000)
15
10
5
0
01-Jul-88
01-Jul-89
01-Jul-90
01-Jul-91
01-Jul-92
01-Jul-93
01-Jul-94
01-Jul-95
TIME
NW rectifier removed April 30, 1 due to a bad Variac. NW Quad connected to SW rectifier.
Conductive Polymer NW
Conductive Polymer SW

Figure 7.3-E Cumulative Current Delivered vs Time
Conductive Polymer NE and SE Quadrant CP Systems

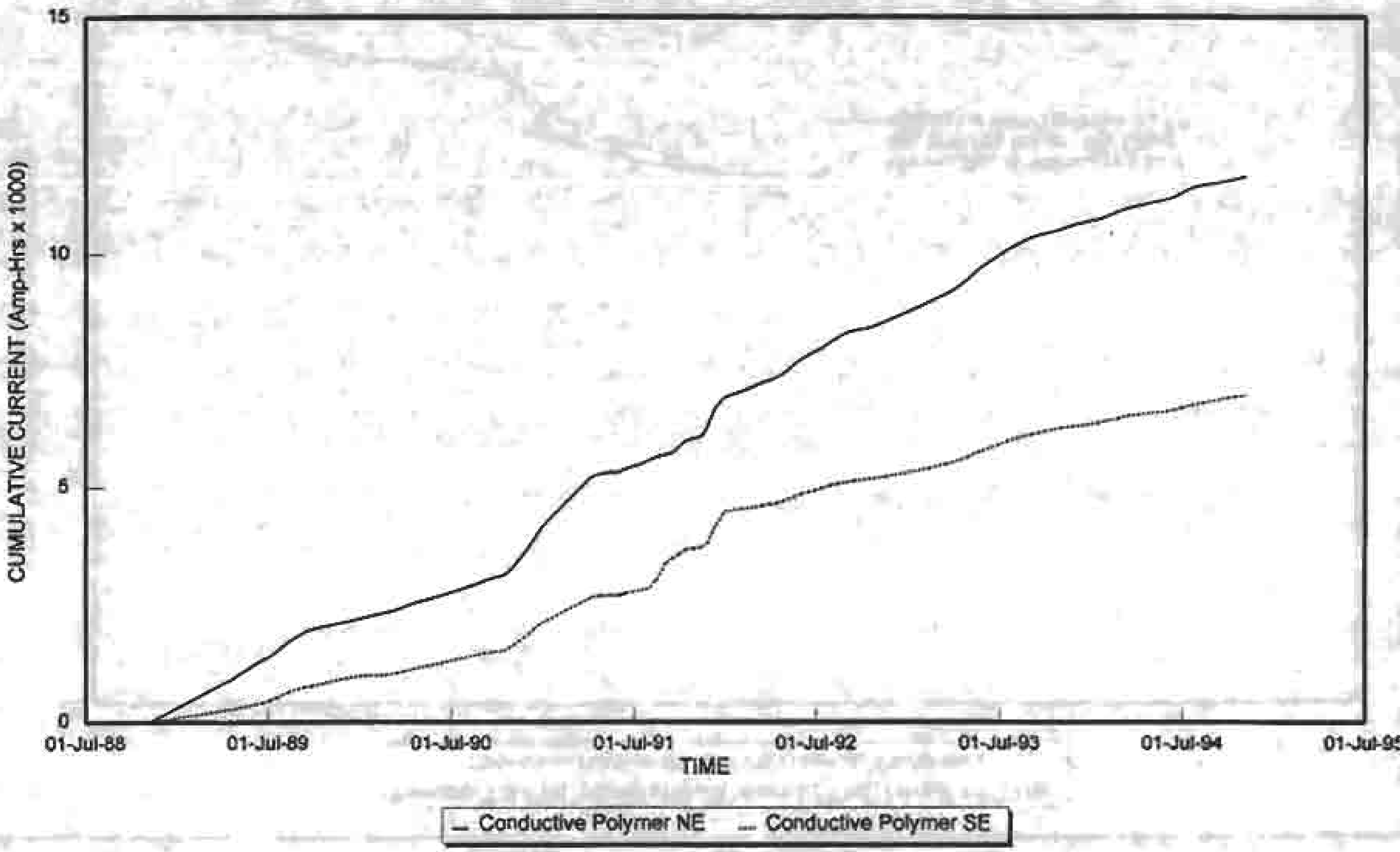


Table 7.3-B

Instant-Off Survey Results
(Negative mV vs Cu/CuSO4)

CP System	Number Of Instant-Off Surveys	On - Potentials			Instant-Off Potentials			Polarization Decay (4 Hour)		
		Avg	Median	Range	Avg	Median	Range	Avg	Median	Range
Coke Breeze	6	591	563	415 - 781	432	412	330 - 586	186	183	105 - 263
Metallized Zinc	6	939	913	551 - 2260	797	773	418 - 2091	409 (1)	347 (1)	181 - 1365 (1)
Raychem	5	496	501	289 - 735	344	346	174 - 572	136	118	19 - 347
Raychem Overlay	4	479	466	380 - 666	477	467	394 - 650	223	235	92 - 370
Eltech	5	471	475	323 - 564	310	308	184 - 415	170	172	80 - 243
Eltech Overlay	5	445	434	243 - 572	436	426	323 - 569	231	242	101 - 310
Conductive Polymer										
NW Quadrant	4	370	368	183 - 694	294	287	144 - 574	117 (2)	80 (2)	7 - 335 (2)
NE Quadrant	5	621	643	259 - 889	444	459	185 - 588	300	316	167 - 440
SW Quadrant	4	595	552	335 - 1051	442	409	268 - 746	230	213	106 - 404
SE Quadrant	5	567	564	389 - 810	441	434	325 - 564	275	260	219 - 386

Note: Averages are weighted based on the number of half-cell readings per instant-off test.
Multiple half-cells were used to perform each instant-off survey.
(1) Large polarization decay values are due in part to electrolytic contact between reference cells and the zinc distribution anode.
(2) Low polarization decay values are the result of a defective rectifier.

Figure 7.3-F Coke Breeze CP System vs Deck Rebar
Corrosion Potentials and Polarization Decay vs Cu/CuSO4; 6 Instant-Off Surveys

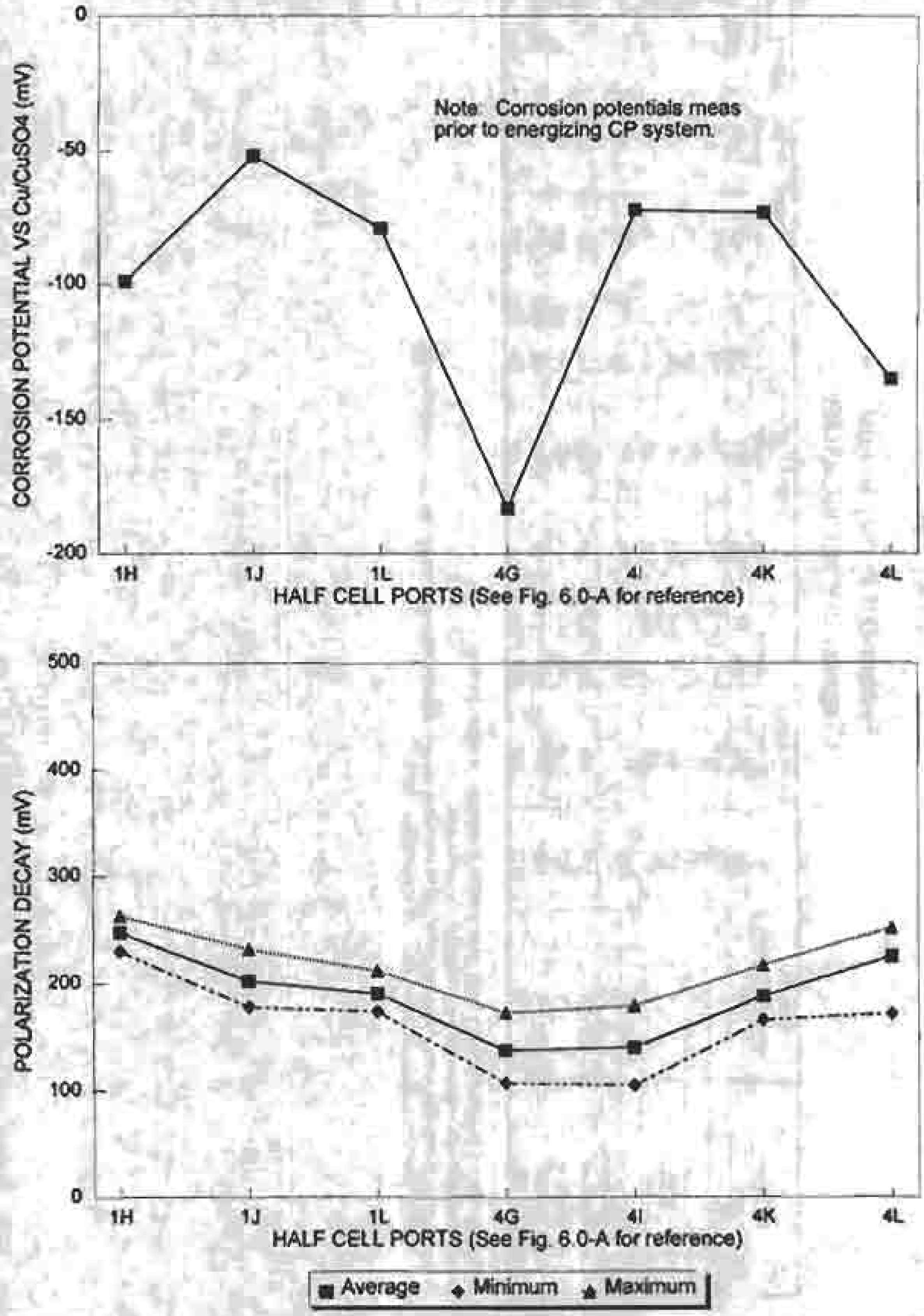
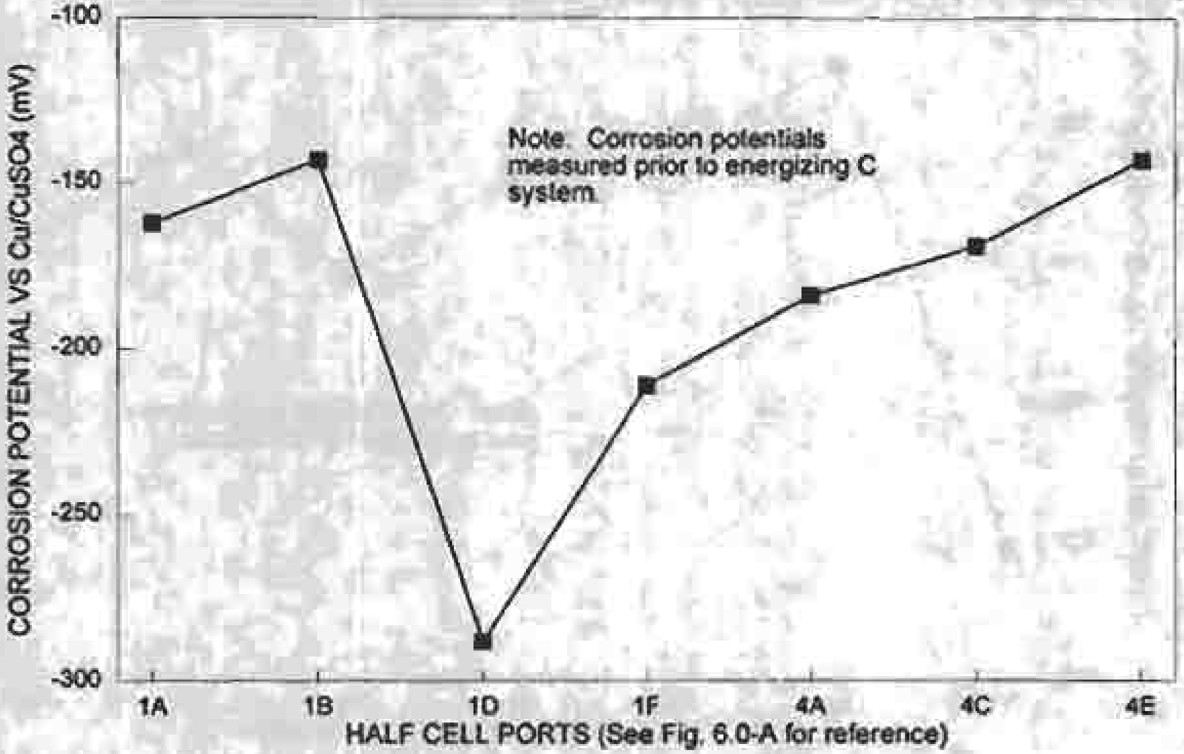
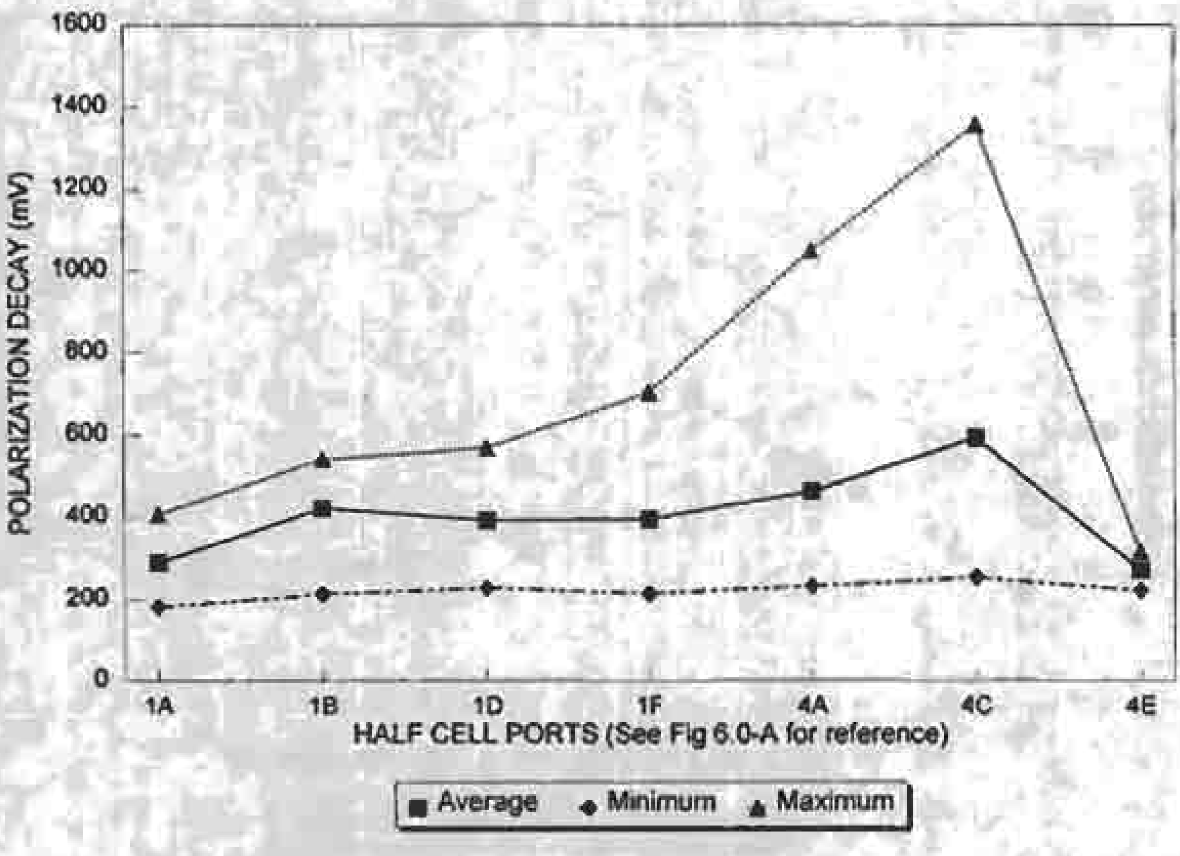


Figure 7.3-G Metallized Zinc CP System vs Deck Rebar

Corrosion Potentials and Polarization Decay vs Cu/CuSO4; 6 Instant-Off Surveys





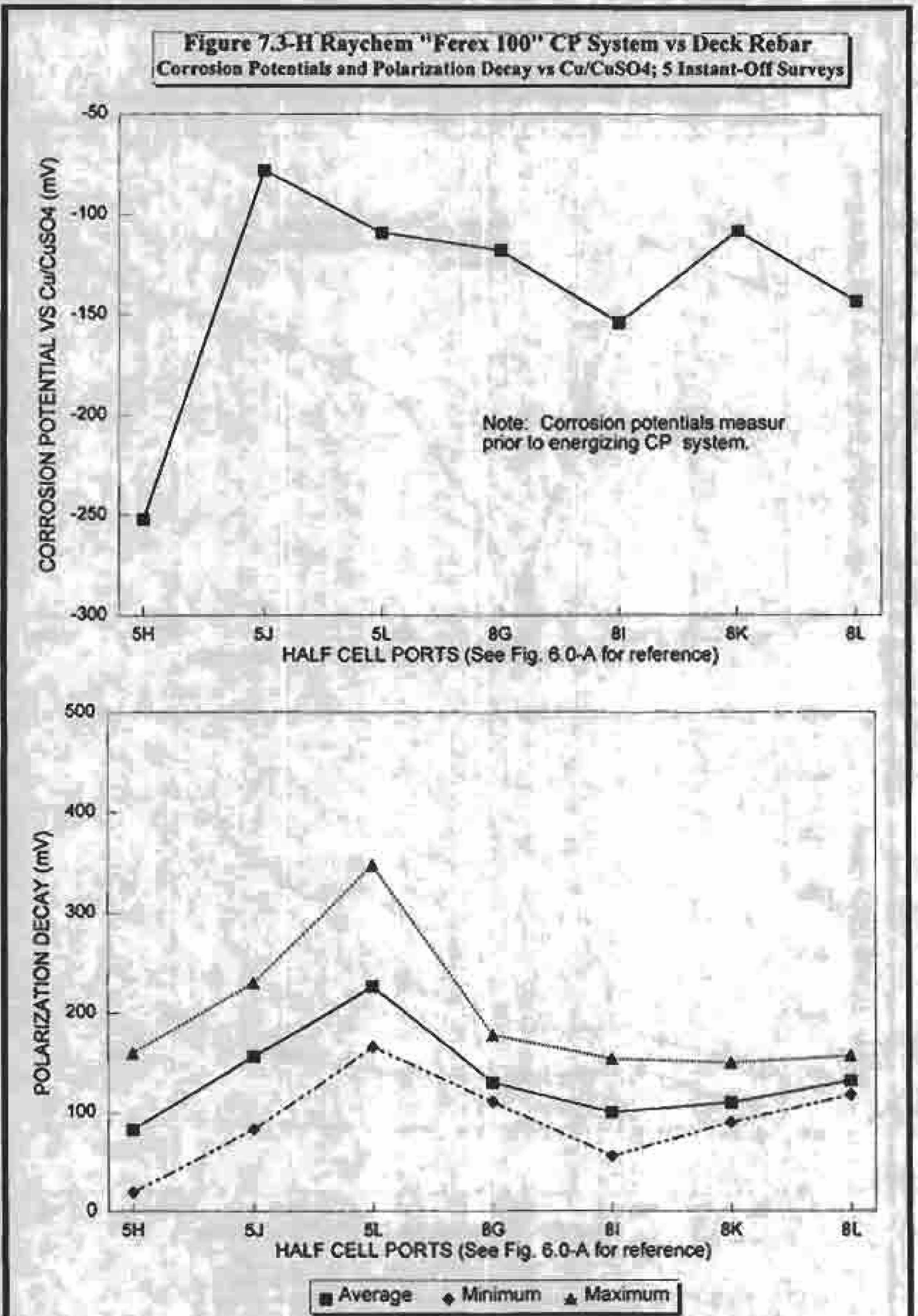
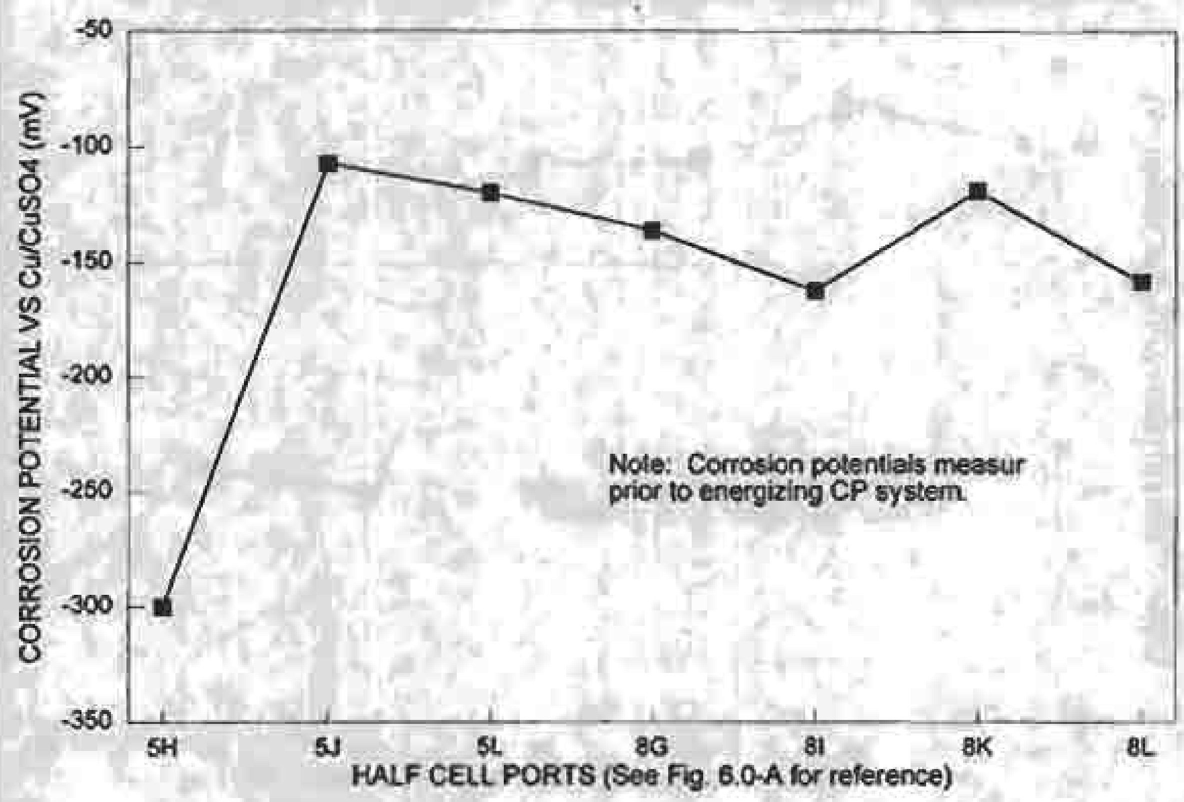


Figure 7.3-H Raychem "Ferex 100" CP System vs Deck Rebar
Corrosion Potentials and Polarization Decay vs Cu/CuSO4; 5 Instant-Off Surveys
CORROSION POTENTIAL VS Cu/CuSO4 (mV)
-50
-100
-150
-200
-250
-300
Note: Corrosion potentials measur
prior to energizing CP system.
5H
5J
5L
8G
8I
8K
8L
HALF CELL PORTS (See Fig. 6.0-A for reference)
POLARIZATION DECAY (mV)
500
400
300
200
100
0
5H
5J
5L
8G
8I
8K
8L
HALF CELL PORTS (See Fig. 6.0-A for reference)
Average
Minimum
Maximum

Figure 7.3-I Raychem "Ferex 100" CP System vs Overlay Rebar
Corrosion Potentials and Polarization Decay vs Cu/CuSO4; 4 Instant-Off Surveys



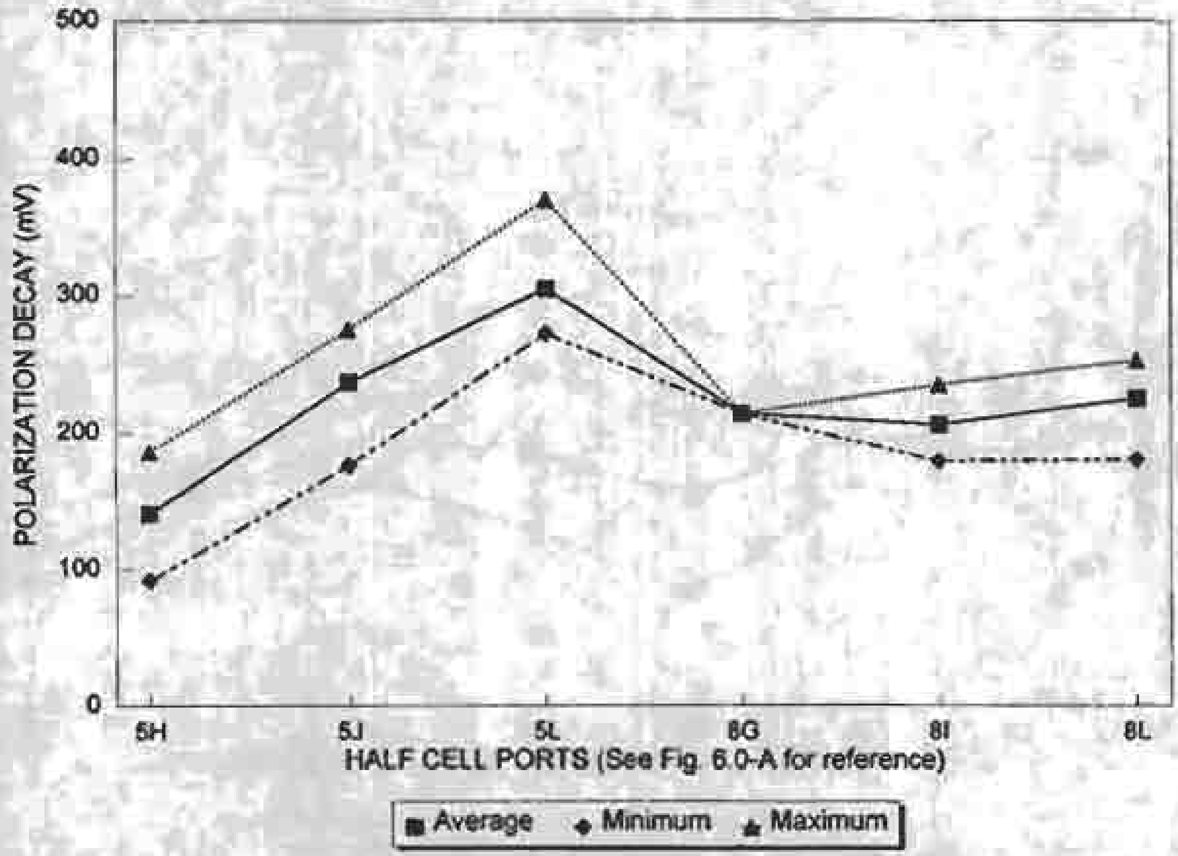


Figure 7.3-J Eltech "Elgard 210" CP System vs Deck Rebar

Corrosion Potentials and Polarization Decay vs Cu/CuSO4; 5 Instant-Off Surveys

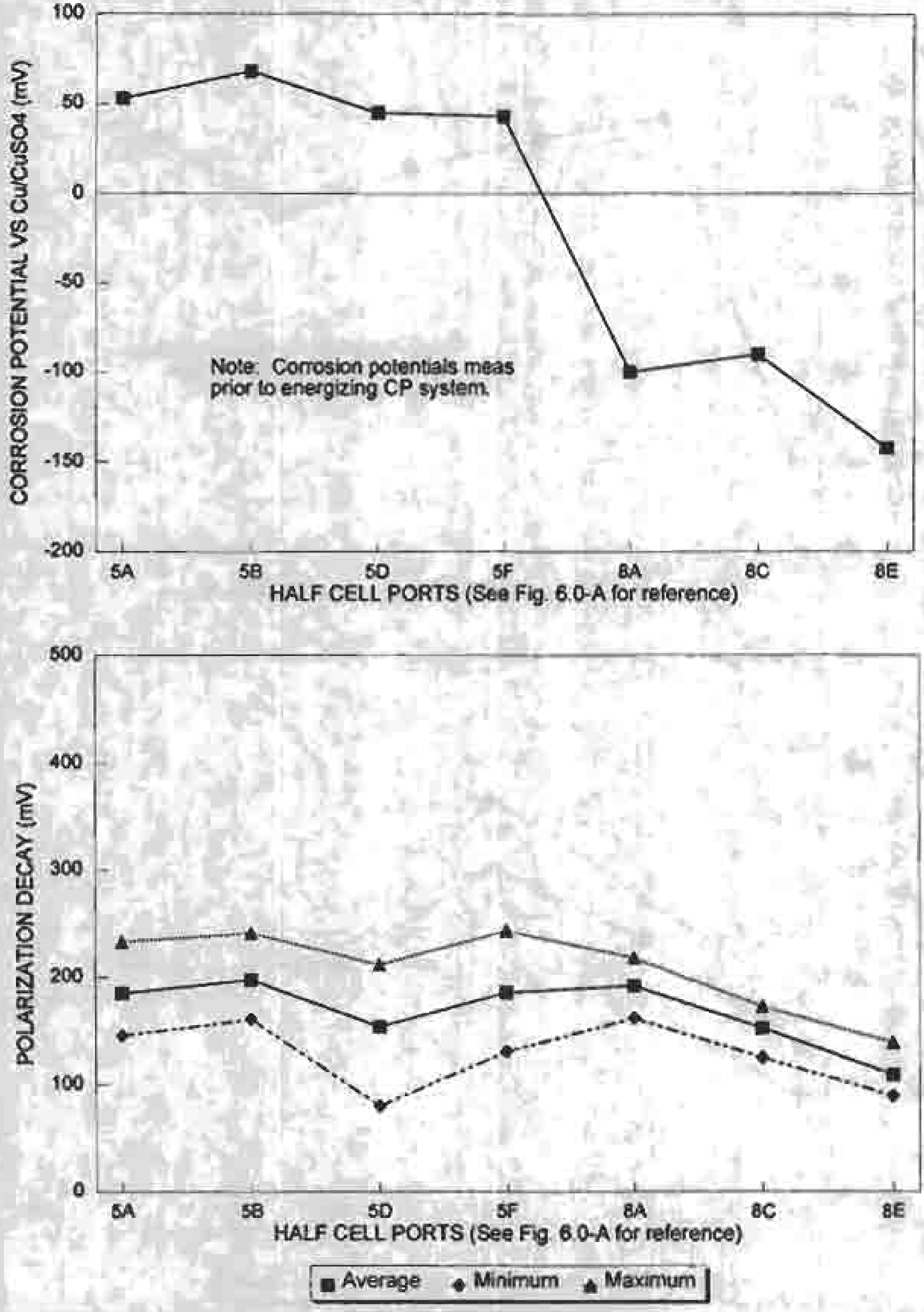


Figure 7.3-K Eltech "Elgard 210" CP System vs Overlay Rebar
Corrosion Potentials and Polarization Decay vs Cu/CuSO4; 5 Instant-Off Surveys

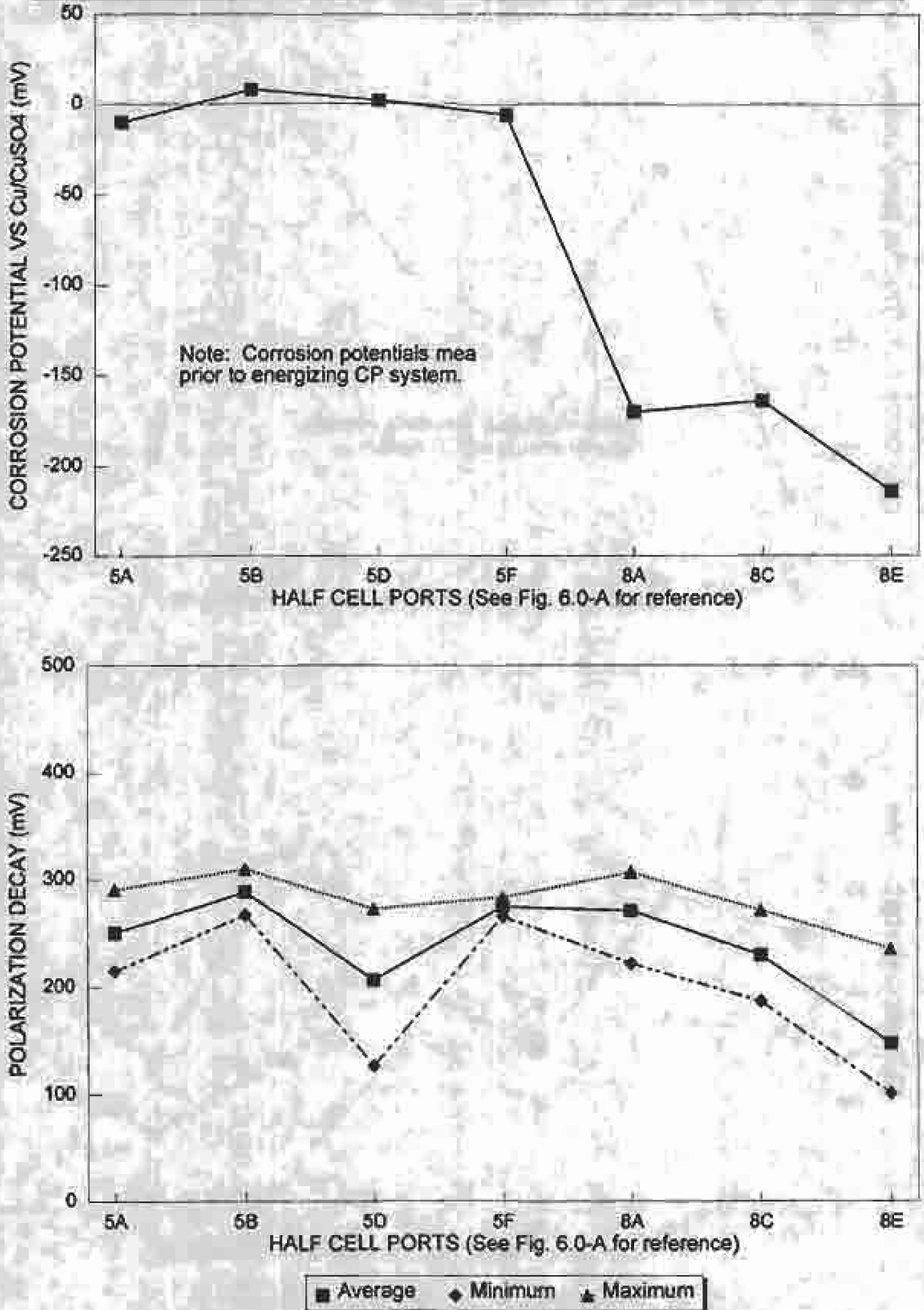


Figure 7.3-L Conductive Polymer CP System (NW & SW Quads) vs Deck Rebar
Corrosion Potentials and Polarization Decay vs Cu/CuSO4; 4 Instant-Off Surveys

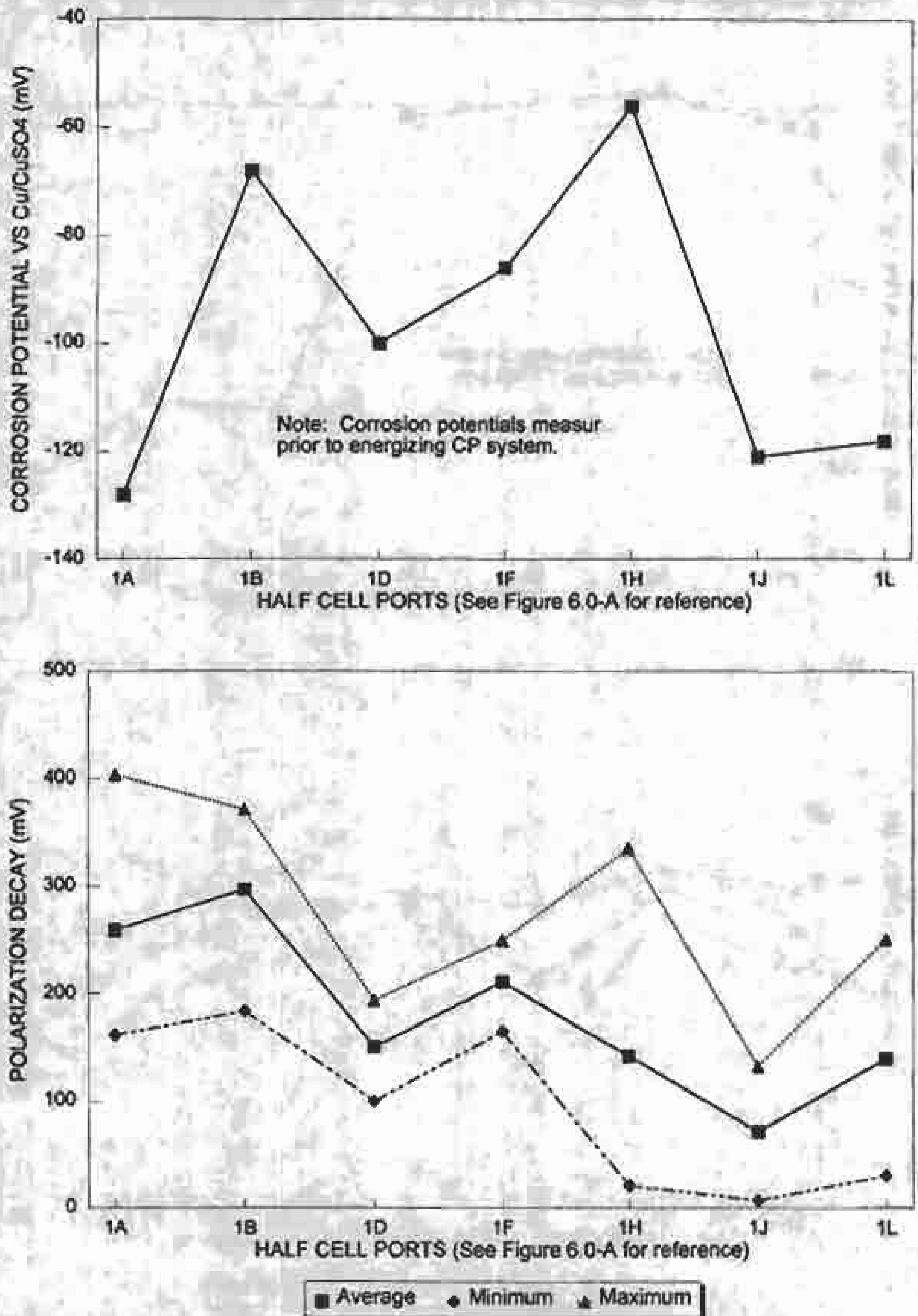
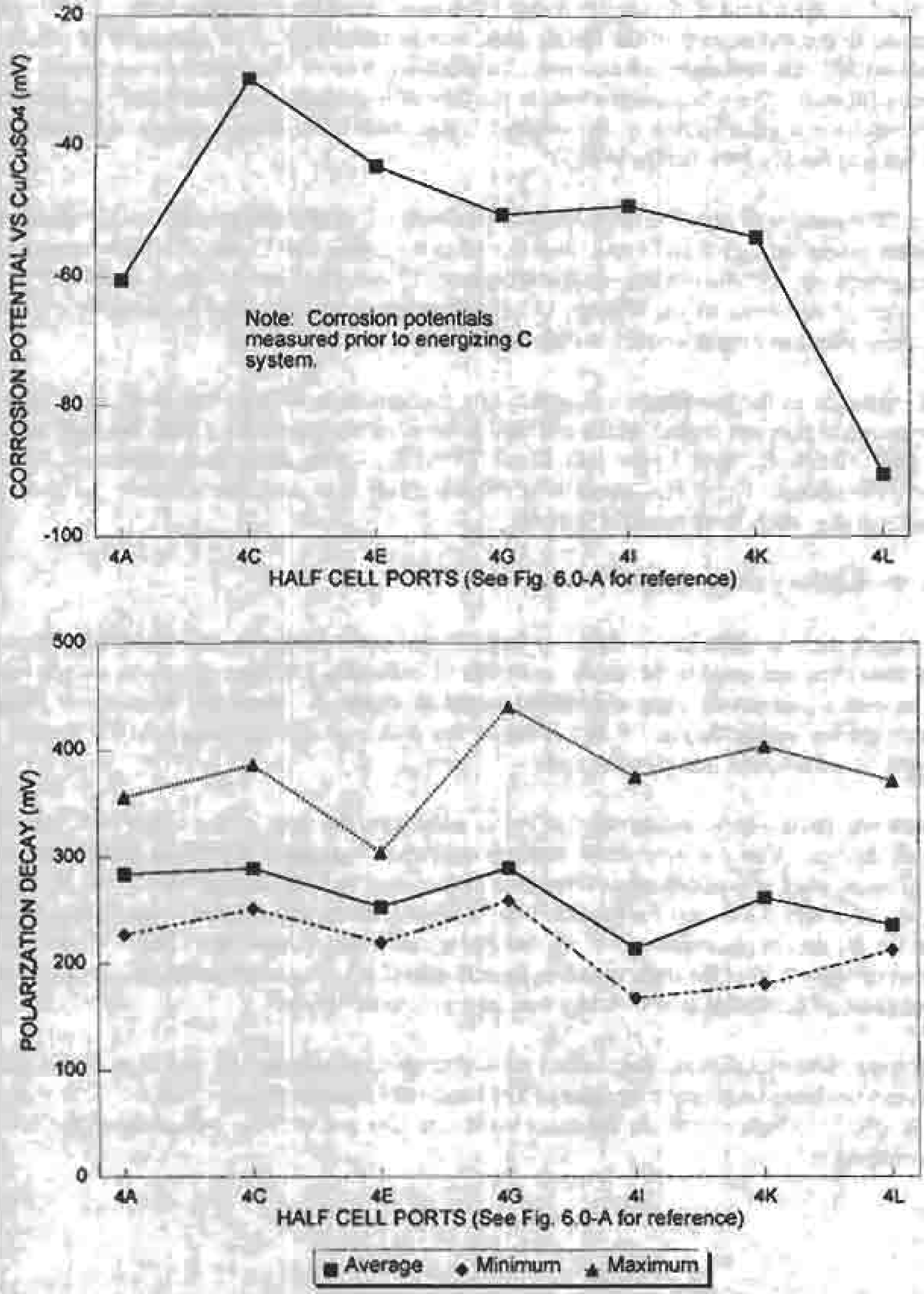


Figure 7.3-M Conductive Polymer CP System (NE & SE Quads) vs Deck Rebar
Corrosion Potentials and Polarization Decay vs Cu/CuSO4; 5 Instant-Off Surveys



8.0 DISCUSSION OF RESULTS

This report has presented the installation and testing results of five independent CP systems applied to three bridge decks for construction and operational comparisons. Each system, applied to the top surface of the bridge deck, was installed to stop the corrosion of reinforcing steel within salt-contaminated concrete. In addition, four of the systems represented typical state-of-the-art CP application methods at the time of installation, and one (the Coke Breeze CP system), was a modification of the original bridge deck CP system designed and installed by Caltrans at the Sly Park Bridge in 1973[1].

The CP current was supplied to the Upper Salt Creek UC (Left) structure by two CP distribution anodes (Metallized Zinc and Coke Breeze), and to the Upper Salt Creek UC (Right) structure by two proprietary CP distribution anodes (Raychem "Ferex 100" and Eltech "Elgard 210"). The CP current delivered to the O'Brien UC (Left) structure was supplied by a newly developed Caltrans anode system (Conductive Polymer).

As presented in the Introduction (Section 1.0), the structures used in this study were part of a previous CP research project which included three other structures along with the right structure of the O'Brien UC and Upper Salt Creek UC (L/R). The other three structures were the Hampshire Rocks UC (Left), North Fork Feather River, and the Lake Almanor Spillway. The results of that study were reported in 1981[2].

8.1 Preliminary Site Results

Although there is sufficient evidence to indicate that some corrosion caused damage existed at the three structures used in this study, as explained in Section 1.0, these structures are not located in an area where severe icing and salting would be expected. However, the range of chloride concentration within the top 25 mm (1 in) of the deck concrete (see Table 7.1-B, Section 7.1) would be sufficient to initiate corrosion.

There was more concrete delamination repair needed on the deck of the Upper Salt Creek UC (Left) bridge. The concrete cover surveys conducted indicate the shallow placement of the reinforcing steel at that structure. Over 15% of that deck had less than 25 mm (1 in) of concrete cover. Surveys conducted on the other two bridges indicated less delamination repair due, in part, to the deeper placement of the top reinforcing steel mat. Upper Salt Creek UC (Right) had approximately 5 % of the deck with less than 25 mm (1 in) of concrete cover, while O'Brien UC (Left) had no detectable area with less than 25 mm (1 in) of cover.

Corrosion potential measurements of all three structures, as indicated by results of deck potential surveys conducted during the summer of 1987 and 1988, were at or more positive -.200 volts (vs. $Cu/CuSO_4$). These potentials indicated corrosion was not actively occurring at the time of measurement.[7]

8.2 Field Installation

The installation of a CP system on a bridge deck can be complex. The installation of five different CP systems on three structures during on contract can only add to this complexity. The difficulty and/or ease of installation of each of these systems varied dramatically.

Table 8.2-A gives the recorded work time in person-days (PD) expended on the installation of each CP system. It should be noted that each system installation has its own "footprint" for worker intensity. The Metallized Zinc CP system used fewer applicators for a longer period of time while the Conductive Polymer CP system required a high concentration of workers for a shorter period of time, primarily because the overlay was mixed at the site.

Table 8.2-A

CP Systems Installation Time Comparison

CP SYSTEM	WORK DONE	TIME (days)	WORKERS (persons)	PERSON DAYS (PD)	ANODE AREA m^2 (ft^2)	WORK RATE m^2/PD (ft^2/PD)
COKE BREEZE	Electrical Work, (Incl. anodes)	6	2	12		
	Coke Breeze	1	6	6		
	AC Overlay	1	6	6		
	TOTAL			24	210.1 (2261.3)	9 (94)
METALLIZED ZINC	Electrical Work, (Incl. anodes)	6	2	12		
	Zinc Stripes	14	3	42		
	AC Overlay	2	6	12		
	TOTAL			66	191.6 (2062.1)	3 (31)
RAYCHEM "FEREX 100"	Electrical Work	5	2	10		
	Anode Cable	2	4	8		
	PCC Overlay	8	10	80		
	TOTAL			98	207 (2223)	2 (23)
ELTECH "ELGARD 210"	Electrical Work	5	2	10		
	Wire Mesh, (Incl. Dist. bars)	2	4	8		
	PCC Overlay	8	10	80		
	TOTAL			98	198 (2136)	2 (22)
CONDUCTIVE POLYMER	Electrical Work	6	2	12		
	Conductive Polymer	3	10	30		
	Non-Cond. Polymer	2	4	8		
	Steel Mesh, (Incl. bus bars)	1	4	4		
	TOTAL			54	377 (4059)	7 (75)

Those systems that used new technology and were unfamiliar to the contract workers (e.g. Metallized Zinc and Conductive Polymer) tended to become more labor intensive due primarily to the unfamiliarity, while others were labor intensive simply due to their complexity alone. However, systems such as the Coke Breeze CP system, were installed faster because workers were more familiar with the process and application equipment used in installation. The application process, texture of material, and equipment used to place the coke breeze and overlay were similar to placing conventional AC overlays.

It should also be noted that weather conditions and the Caltrans initiated changes caused some increases in application time. The Caltrans requirement of a thicker concrete overlay with reinforcing steel to be applied over the two proprietary CP systems (Raychem and Eltech) caused a work time increase. The difficulty of placing the concrete overlay during days that the temperature exceeded 43 °C (110 °F) also increased the application time.

The rectifiers used for the CP systems were existing from the previous CP systems used on these structures. Only minor re-wiring was needed to re-direct the CP current to the newly installed systems.

The following paragraphs discuss conditions specific to each CP system.

COKE BREEZE CP SYSTEM: The coke breeze distribution anode mix differed from that in the contract specifications. The coke breeze supplied, the only one available to the contractor at the time, had the gradation indicated in Table 5.3-A, Section 5.3. Since it was felt that this predominantly single gradation would produce an unstable layer under the AC overlay wear surface, an alternative mix design was used.

In order to increase stability, laboratory stability tests were conducted on coke breeze samples containing various gradings of coarse and fine mineral aggregate. The result was a mix design (see Table 5.3-B, Section 5.3) that was similar to that designed by the Ontario, Canada, Ministry of Transportation and Communications. When compacted and tested in accordance with the existing Canadian specification,[8] had a resistivity less than 1 ohm-cm and a stability value of 28.

The Coke Breeze was the easiest CP system to install and seemed to create the least worker apprehension, based on the number of questions and directions required by the contractor. By using familiar materials and equipment, a minimum of lead time was necessary.

One difficulty, however, had to be overcome. It was hard to add the mineral aggregate to the coke breeze mix. Because of the density difference between the coke breeze and the mineral aggregate, the mixing could not be done in an AC stack plant. A continuous drum plant, capable of blending the mix properly without separation was needed. Unfortunately, the only available drum plant could not proportion the required asphalt in excess of 9.9%. The mix needed 13% asphalt.

The problem was solved by first blending the mix in the continuous drum plant (dry) and then transporting the mix to the stack plant where the asphalt was added (with screeds removed to minimize re-separation of the blended mix). This process, though complex, worked quite well.

Four primary anodes were placed in each shoulder of the deck for both the Coke Breeze and the Metallized Zinc CP systems. This orientation was chosen so they would be outside the wheel track of the traffic lanes. This was done to prevent potential damage caused by vehicle wheel loading.

METALLIZED ZINC CP SYSTEM: Since extra zinc was applied over the top of the brass pads, there was concern that the metallized zinc coating would become disbonded at those locations. To remedy this situation, stainless steel machine screws, #10-32 x 9.5 mm (3/8 in), were drilled and tapped through the zinc coating into the brass pad to maintain continued electrical contact.

The metallized zinc was applied in stripes to ensure that there was some clear area between each stripe for the AC overlay to bond to the concrete deck. However, no testing was done to determine how much clear concrete surface area was needed to prevent slippage of the AC overlay.

No effort was made to determine the bond strength of the metallized zinc coating on the concrete surface although visual observations determined that the zinc was bonded. Any areas that were obviously disbonded were stripped of the loose metallized zinc and the surface cleaned and re-roughened. The metallized zinc was then re-applied to these areas.

The method of using the stranded wires encapsulated in the zinc stripe to deliver current to the deck was tested against the use of brass anode pads to deliver current. Anomalous readings obtained during several polarization decay tests at various half-cell ports made the evaluation of this method difficult. At this time, it is uncertain if the method could be used to replace the brass anode pads.

RAYCHEM "FEREX 100" CP SYSTEM: Design and installation procedures were provided by the manufacturer, but some deviations were made during the installation of the Ferex 100 system. The thickness of the concrete overlay was increased to allow placement of a #10M epoxy coated reinforcing steel mat within the overlay. This was done so that the overlay could withstand the high traffic volume and heavy truck loads that are common on this route. Also, due to concern that stray current from the deck CP system would result in damage to the overlay reinforcing steel, a separate CP system was installed using the same Ferex 100 anode cable to protect the overlay mat.

ELTECH "ELGARD 210" CP SYSTEM: Additional plastic cleat anchors were placed to hold the Elgard 210 mesh in place. Workers walking over and moving equipment across the mesh caused it to stretch and ride up away from the concrete deck surface. Because the overlay reinforcing steel mat was spaced only 38.1 mm (1-1/2 in) above the deck, there was some concern that the mesh would lift up and come in contact with the rebar mat causing a short circuit in the CP system. Through constant monitoring and the placement of additional cleats, the mesh was kept in place on the deck.

The concrete overlay placed on the Upper Salt Creek UC (Right) is showing signs of transverse and longitudinal hairline cracking in a pattern matching the 305 mm (12 in) square grid pattern of the overlay reinforcing steel. It is suspected that the cracking was induced by concrete shrinkage. There are no other signs of distress on this deck.

CONDUCTIVE POLYMER CP SYSTEM: The mixing sequence and procedures used during placement of the conductive polymer on the O'Brien UC (Left) required close scrutiny because there were differences in the densities and absorptive qualities of the mineral aggregate and coke breeze being mixed.

The conductive polymer mix procedure, as prescribed, was to first place the heavier mineral aggregate (pea gravel) in the mixer along with the polymer resin that had been catalyzed and thoroughly blended. To this mixture, the progressively lighter materials were sequentially added (e.g., sand, coke breeze, and fluid coke breeze). Using this technique, all surfaces of the filler materials were thoroughly wetted during the mixing process.

Since the conductive polymer was first placed on lane #2 of O'Brien UC (Left), mixing procedures were followed closely. During the placement operation, it was discovered that the last barrel of polyester resin was found to be out of specification. At this point, the pour was terminated approximately 3 m (9 ft) from the end of the structure, and a 127 mm (5 in) wide paving notch was formed at the end of the pour so that the subsequent overlay extension would be able to bond to the terminated end of the overlay. The primary anode wire mesh was not cut. Instead, it was left in place to provide electrical continuity. After receipt of new polyester resin, this area was re-sandblasted and re-primed prior to placing the remainder of the conductive polymer overlay.

During the placement of the conductive polymer overlay on lane #1, the mixing sequence was inadvertently not followed as closely as it should have been. Several batches of material were not thoroughly mixed. Additionally, one batch was mixed without the addition of the catalyst. This batch failed to cure properly on the deck.

As a result of those complications, approximately 7 m^2 (70 ft^2) of the lane #1 overlay was either uncured or disbonded from the bridge deck. A saw-cut was made around the periphery of those areas, cutting through the overlay and the wire mesh primary anode, and all uncured material and wire mesh was removed. The removed areas were sandblasted, re-primed, the wire mesh primary anode replaced and retied to the existing mesh. This patching method was evidently successful, since those areas have shown no additional distress to date.

Due to the low resistivity (<2.0 ohm-cm) achieved with this conductive polymer overlay mix design, future designs using this mix may not require the extensive use of a primary anode wire mesh grid, or at most, a reduced amount would be needed.

Some portions of the polymer overlay are cracking and rust stains have appeared over some locations where the wire mesh primary anode wire and the #3 rebar bus bars are embedded. We believe the surface cracks in these areas were caused from the combined effects of having the wire mesh in close proximity to the surface of the overlay and having the build up of shrinkage stresses within the polymer overlay.

The promoter/hardener shall consist of a promoter compatible with suitable methyl ethyl ketone peroxide (MEKP) and cumene hydroperoxide initiators to provide the desired gel times. The peroxide/resin percentage shall be adjusted in the field as conditions warrant to provide a minimum 45 minutes gel time.

Concrete mineral aggregate for polyester concrete shall conform to the quality requirements of Section 90-2.02, "Aggregates," of the Caltrans Standard Specifications and shall comply with the following limits for combined grading:

COMBINED MINERAL AGGREGATE

SIEVE SIZE	% PASSING
9.5 mm (3/8")	100
No. 4	45 - 65
No. 8	34 - 55
No. 16	24 - 45
No. 30	15 - 35
No. 50	4 - 19
No. 100	0 - 7
No. 200	0 - 3

Concrete mineral aggregate retained on the No. 16 sieve, when combined, shall have a maximum of 30 percent crushed particles when tested in accordance with California Test 205.

Concrete mineral absorption shall not exceed one percent as tested in accordance with California Test 226.

The calcined coke breeze aggregate shall be commercial quality as defined by ASTM D-121 and shall comply with the following gradation limits:

The current density of each CP system exhibited similar delivery characteristics with a few exceptions. Even though each CP system achieved an average polarization decay value exceeding the 100 mV as recommended by NACE[5], some differences between each system can be noted as shown in Table 8.3-A.

Table 8.3-A

Comparison of Average Values Between CP System, Driving Voltages, Current Densities, and Polarization Decays

STRUCTURE	CP SYSTEM	DRIVING VOLTAGE Volts	CURRENT DENSITY mA/m^2 (mA/ft^2)	POLARIZATION DECAY mV
Upper Salt Creek UC (Left)	Coke Breeze	2.34	6.46 (0.60)	186
	Metallized Zinc	1.45	6.03 (0.56)	409***
Upper Salt Creek UC (Right)	Raychem	2.42	4.74 (0.44)	136
	Raychem Overlay	2.20	7.86 (0.73)	223
	Eltech	1.25	6.46 (0.60)	170
	Eltech Overlay	1.21	10.55 (0.98)	231
O'Brien UC (Left)	Polymer (NE)	2.89	5.27 (0.49)	300
	Polymer (SE)	1.95	3.55 (0.33)	275
	Polymer (NW Only)	1.32*	2.48 (0.23)*	117
	Polymer (SW Only)	2.37*	3.01 (0.28)*	230
	Polymer (NW & SW)	2.75**	4.20 (0.39)**	-

Data presented in this table has been presented previously in more detail in Tables 7.2-A, 7.3-A, and 7.3-B.

* Data reflects analysis of measurements taken on these systems up to April 30, 1992.
**Data reflects analysis of measurements taken after April 30, 1992 when NW Quadrant was connected to SW Quadrant rectifier.
***Large polarization decay values are due in part to electrolytic contact between reference cells and the zinc distribution anode.

The average current density of the Raychem CP system was slightly lower than that of the Eltech, Coke Breeze, and Metallized Zinc Deck CP systems located on adjacent bridge decks. This difference is also reflected in the lower average 4 hour depolarization decay values and the higher average driving voltage of the Raychem system when compared to the other systems.

The calculations to determine the total area of exposed steel in the epoxy coated steel overlay rebar mats used the following assumptions: (a) The maximum allowable unrepaired, damaged area of the epoxy coating was 2 percent, or less, of total bar surface area[10], and (b) Additional damage would occur after placement due to rebar chafing at points of intersection. The chafing damage was assumed to occur at 30% of the intersection points and the assumed damage area was approximately 6.45 mm^2 (0.01 in^2) per intersecting point.

The reason for the lower efficiency of the Raychem system is unclear. Possible causes include premature anode degradation and embrittlement as has been noted in other installations. The Ferex 100 anode requires the full circumferential area to deliver the recommended current output

The conductive polyester concrete shall be mixed and placed as follows:

MIXING. The polyester resin shall be initiated and thoroughly blended prior to introduction of aggregate to the binder. Mixing time will be a minimum of two minutes after introduction of aggregates. Cleaning up of equipment with solvents shall be done in a environmentally safe manner that will not contaminate prime coat or overlay concrete.

PLACING. The conductive polyester concrete shall be placed prior to gelling and within 10 minutes after initiating resin.

Should the rate of hardening be too fast, the amount of peroxide may be decreased to a minimum of 1/2 percent by weight. If the desired rate of hardening is too slow, additional peroxide may be added to a maximum of 4 percent.

STEEL WIRE MESH. Steel wire mesh shall conform to the details shown on the plans and the provisions in Section 52, "Reinforcement" of the Caltrans Standard Specifications and these special provisions.

Steel wire mesh and connecting leads shall be placed on the prepared concrete deck after the prime coat has been placed and hardened to a tack-free state and before placing the conductive polyester overlay. Steel wire mesh shall be electrically continuous and shall be placed in such a manner as to ensure a minimum top cover of 12.7 mm (1/2 in) and minimum 3.2 mm (1/8 in) between the wire mesh and the prime coat. Holes drilled or driven into the deck to support the wire mesh shall be cleaned or isolated so that no conductive paths will exist between the prime coat or overlay and the reinforcing steel in the deck. Spacers used to keep the mesh off the concrete deck shall be of a electrically nonconductive material. There shall be no coatings or rust on the mesh that would impair electrical contact between the mesh and the polyester concrete. The conductive polyester overlay shall be placed in such a manner that the wire mesh and connecting leads will not be damaged.

NONCONDUCTIVE POLYESTER CONCRETE INSULATING BARRIER. This work shall consist of preparing concrete surface, applying nonconductive prime coat, and placing 0.6 m (2 ft) wide nonconductive polyester concrete electrical insulating barrier strips in accordance with the details shown on the plans and the requirements in these special provisions.

Care shall be taken to ensure that there are no electrically conductive paths between the conductive polyester concrete overlays and the barrier strips. This includes but is not limited to any conductive prime coat or conductive polyester concrete found in the area of the barrier strips.

The longitudinal nonconductive polyester concrete barrier shall be centered between traffic lanes along the lane line.

Any area that becomes contaminated shall be recleaned by abrasive blasting at the Contractor's expense.

Again in November 1994, the Metallized Zinc and Coke Breeze CP systems were independently checked by a second corrosion engineering firm[14] contracted by SHRP. The Introduction, Conclusions, and Recommendations of this study are reprinted, in part, in Appendix 10.12 of this report.

8.4 Life Expectancy

Most bridge deck cathodic protection distribution anodes have only recently been developed. For that reason, determining the actual life expectancy of any one system can only be estimated. The first bridge deck CP system was installed approximately 22 years ago by Caltrans and was followed almost immediately by similar coke breeze CP installations in Canada. Most of the remaining systems have been operating for less than 15 years.

Because of this short historical period, the life expectancies of existing CP systems must either be extrapolated from data recovered from those systems or from the results of accelerated life tests conducted in the laboratory. Caution should be used with these estimations because anode consumption, while a major component of the evaluation, is not the only cause for system failure. Other types of failure can include breakdown of the conductive materials within the distribution anode, disbondment from the deck, and isolation between conductive components within the distribution system.

The life expectancy of the five deck CP systems evaluated in this study is estimated as follows based on information referenced below:

Coke Breeze CP System:	20 Years	(1)
Eltech "Elgard 210" CP System:	35 Years	(2)
Raychem "Ferex 100" CP System:	Unknown	(3)
Metallized Zinc CP System:	< 20 Years	(4)
Conductive Polymer CP System:	> 40 Years	(4)

(1) Caltrans' experiences with Coke Breeze CP systems supports the 20 year estimated life expectancy of that type of CP system. This estimate may, however, be low. The Sly Park Bridge Coke Breeze CP system,[1] the first bridge deck CP system to be installed, is presently still operating satisfactorily after 22 years of continuous operation.

(2) Life expectancies as presented in the SHRP report "Cathodic Protection of Concrete Bridges: A Manual of Practice."[15]

(3) Reported as follows, in the draft of the SHRP "State-of-the-Art" report:[16] "By 1990, several field installations were exhibiting problems with anode degradation and embrittlement, evidently due to local hot spots. Thus, this anode is not widely used today."

(4) The life expectancy of these systems have been calculated based on the data recovered from the installations from this project and accelerated laboratory tests on the material used.[12] Additionally, life expectancy data presented in the initial report on the East Camino UC

Polyester styrene concrete overlay surfaces shall receive an abrasive sand finish. The sand shall be commercial blast sand conforming to the aggregate dryness requirements of these special provisions and the following gradation limits:

SAND FINISH GRADATION

SIEVE SIZE	% PASSING
No. 8	100
No. 30	0

The abrasive sand finish shall be applied immediately after overlay strike-off. Sand shall be broadcast onto the surface before gelling occurs to effect a coverage of 0.3 to 0.5 kg/m^2 (0.6 to 1.0 lbs/yd^2).

The finish surface of the conductive polyester overlay including the insulating barrier strips shall conform to the provisions in Section 51-1.17, "Finishing Bridge Decks" of the Standard Specifications and these special provisions.

Grooving or grinding shall not expose steel wire mesh. Exposed or damaged wire mesh shall be repaired to the Engineer's satisfaction at the Contractor's expense.

No traffic or Contractor's equipment shall be allowed on the overlay before a period of four hours has elapsed after the final finish.

The polyester concrete surface shall be protected from rain or contact with water for a minimum of six hours after placement.

Prior to constructing the overlays, one or more trial overlays complete with prime coat and wire mesh shall be placed on previously constructed concrete base to demonstrate the effectiveness of the mixing, placing, finishing and texturing equipment. Trial overlay slabs shall be 3.66 m (12 ft) wide, at least 1.33 m (6 ft) long, and the same thickness of the overlay to be constructed.

All materials used in the trial slabs, including the concrete base, shall become the property of the Contractor and shall be disposed of as provided in Section 7-1.13, "Disposal of Material Outside the Highway Right of Way," of the Caltrans Standard Specifications.

ELECTRICAL CONNECTOR. Eight gauge wire lead stranded HWMPE (high molecular weight polyethylene) shall be CADWELDED to the rebar as shown on the plans. The wire lead shall be of sufficient length to extend from rebar to junction box under the bridge deck. The welded connection shall be insulated using standard practice for insulating "Direct Burial Insulation" of conductors. The rebar shall be tied as shown on the plans.

9.0 REFERENCES

1. Chang, G.C., Apostolos, J.A., Myhres, F.A., "Cathodic Protection Studies of Reinforced Concrete," California Department of Transportation, Division of New Technology, Materials & Research, Report No. FHWA/CA/TL-81/02, 1981.

2. Jurach, P.J., "An Evaluation of the Effectiveness of Cathodic Protection of Seven Bridge Decks," California Department of Transportation, Division of Structures, Report No. FHWA/CA/SD-80/1, December 1981.

3. Carello, R.A., Parks, D.M., "Cathodic Protection of a Reinforced Concrete Bridge Deck and Soffit Using Metallized Zinc," California Department of Transportation, Division of New Technology, Materials & Research, Report No. FHWA/CA/TL-91/05, September 1991.

4. Ministry of Transportation and Communications, Special Provisions Number 312, "Electrically Conductive Mix," Ontario, Canada, February 1986.

5. NACE Standard Recommended Practice, "Cathodic Protection of Reinforcing Steel in Atmospherically Exposed Concrete Structures," NACE Standard RP0290-90, Item No. 53072, National Association of Corrosion Engineers, Houston, TX, April 1990.

6. California Test 404, "Methods of Test for the Chemical Analysis of Portland Cement." California Testing Manual, Testing and Control Procedures, California Department of Transportation, Division of New Technology, Materials and Research, 1986.

7. ASTM Designation C-876, Standard Test Method for "Half-cell Potentials of Uncoated Reinforcing Steel in Concrete," 1987.

8. California Test 366, "Method of Test for Stabilometer Value." California Testing Manual, Testing and Control Procedures, California Department of Transportation, Division of New Technology, Materials and Research, 1978.

9. Ministry of Transportation and Communications, Laboratory Testing Manual, Test Number LS-286, "Method of Test to Measure Resistivity of Conductive Asphalt Mixtures," Ontario Canada, 1984.

10. Metco Inc., "Flame Spray Handbook," Vol. 1, Metco Inc., Westbury, Long Island, New York, 1969.

11. California Department of Transportation Special Provisions, SSP # B-52.64, "Epoxy Coated Reinforcing Steel," 1988.

12. Flora, K.S., Heinley, J.C., Carello, R.A., "The Accelerated Performance of Laboratory Conductive Polymer Cathodic Protection Test Specimens," California Department of Transportation, Division of New Technology, Material & Research, Report No. F89TL01, June 1990.

Polyester reinforcing fibers shall be those sold under the trade name "BoniFibers B" or equal and conforming to the following requirements:

AVERAGE DIAMETER: 0.0203 mm ± 0.0025 (0.0008 in ± 0.0001)
SPECIFIC GRAVITY: 1.32 to 1.40
MELT TEMPERATURE: 249°C (480°F) minimum
IGNITION TEMPERATURE: 538°C (1000°F) minimum
TENSILE STRENGTH: 517103 kPa ± 34473 kPa (75000 psi ± 5000 psi)
BREAK ELONGATION: 33% ± 9%

Polyester reinforcing fibers shall be approximately 6.35 mm (1/4 in) long.

Polyester reinforcing fiber shall be added to asphalt concrete at rate of 1 kg per 400 kg (5 lbs per ton) of asphalt concrete.

When polyester reinforcing fibers are added, the amount of paving asphalt used in the mix shall be increased by 0.25% of the weight of the mix.

The contract price paid per pound for pavement reinforcing fibers shall include full compensation for furnishing all labor, materials, tools, equipment, and incidentals and for doing all the work involved in furnishing, delivering, and introducing pavement reinforcing fibers into the asphalt concrete mix, complete in place, including additional paving asphalt, as shown on the plans, as specified in the Caltrans Standard Specifications and these special provisions, and as directed by the Engineer.

10.7 Controlled Slump Concrete Overlay Specifications

CONTROLLED SLUMP CONCRETE OVERLAY. The work under this section consists of removing the portland cement concrete surface from bridge deck and bridge approach, furnishing and placing controlled slump concrete overlay in accordance with the details shown on the plans, as provided in the Caltrans Standard Specifications and these special provisions and as directed by the Engineer.

REMOVE PORTLAND CEMENT CONCRETE SURFACE. The method of removing 6.25 mm (1/4 in) of portland cement concrete surface from bridge deck and varying thickness at bridge approach shall be selected by the Contractor. Equipment or procedures that damage the remaining concrete surface, as determined by the Engineer, shall not be used.

Removing equipment shall be power operated, mechanical, and capable of removing the existing concrete to the depth specified.

The removing method shall be such that all fractured material can be removed by air-blast. Equipment or procedures which leave fractured concrete or aggregate embedded in the concrete surface will not be permitted.

The entire area to be resurfaced shall be cleaned by abrasive blasting, not more than 24 hours before placement of the concrete overlay, to remove laitance and surface contaminants.

10.0 APPENDICES

The specifications reprinted in Appendices 10.1 through 10.7 have been condensed from those published in the Contract Special Provisions used during the construction of this project.

Not all sections of the Contract Special Provisions have been reprinted. Only those items that may help to clarify the installation processes as described in this report are included.

10.1 Coke Breeze CP System Specifications

COKE BREEZE ASPHALT CONCRETE. Coke breeze asphalt concrete shall conform to the provisions of Section 39, "Asphalt Concrete," of the Caltrans Standard Specifications and these special provisions.

Coke breeze shall be used instead of mineral aggregate. Coke breeze shall be commercial quality as defined in ASTM Designation: D121.

The grading of the coke breeze shall be 9.5 mm (3/8 in) maximum, based on laboratory tests prior to entry into the drier.

**** (NOTE: The coke breeze gradation and mixing specification was changed during construction. Mineral aggregate was added to the coke breeze to improve the stability of the mix which also resulted in a reduction in the "percent by weight" amount of the asphalt binder added -- see new description in Section 5.3 of this report). ****

The Contractor's attention is directed to the characteristic features of coke breeze material. It heats rapidly and is highly absorbent.

The asphalt binder to be mixed with aggregate shall be between 17 percent and 22 percent by weight of the dry aggregates as determined by the Engineer.

Mixing time of coke breeze asphalt concrete shall be one minute, or as directed by the Engineer.

In advance of spreading coke breeze asphalt concrete, the surfaces to receive the coke breeze asphalt concrete shall be prepared as specified for "Prepare Concrete Deck Surface" under the "Metallized Zinc CP System Specification" elsewhere in these special provisions (see Appendix 10.2 of this report).

Paint binder shall be RS-1 Type asphalt emulsion applied in one application to areas to be covered by coke breeze asphalt concrete at a rate of 0.23 L/m^2 (0.05 gal/yd^2) .

Coke breeze asphalt concrete shall be placed in one layer to the compacted thickness specified on the plans. Placing equipment shall be equipped with pneumatic tires. It shall be spread at such temperature that rolling shall be performed when the temperature of the mixture is between 93 and 121°C (200 and 250 °F).

Tests were conducted after 3.4 years of CP delivery at several of these areas where surface cracking was found. These areas were excavated to expose the wire mesh primary anode and the depth of the wire mesh below the surface of the overlay was measured. Cracks were evident where the cover over the wire mesh was less than 17.46 mm (11/16 in). No cracks in the conductive overlay were observed where the depth of the wire exceeded 17.46 mm (11/16 in).

The low cover depth of the wire mesh in the overlay surface may have resulted because it was very difficult to make the steel mesh "lay flat" on the deck during its placement. Furthermore, the accurate placement of the mesh was critical since only a thin overlay was used, less than 44.45 mm (1-3/4 in) average. Hopefully, this shortcoming will be alleviated in future overlay designs since the need for the steel mesh will be eliminated or reduced.

Preliminary laboratory tests performed on samples of the conductive polymer mix were subjected to a "water soak" test for 6 months. The samples were dried and weighed prior to the test and again weighed after the 6 month test period. The results indicated a total weight gain of approximately 1/4 %.

Based on the results of these preliminary tests, it was assumed that since the polymer mix seemed to be impervious to moisture, the initial overlay cracking was probably caused by shrinkage stresses in the overlay. Once the cracks appeared, moisture migrated down to the primary anode wire mesh and caused the wire to corrode. The continued cracking of the overlay was probably due to the expansion pressure caused by the corrosion products of the exposed wire mesh primary anode during CP current delivery.

Additionally, laboratory testing was conducted and reported[12] on reinforced concrete samples made from the applied conductive polymer mix and primary anode wire used during the construction phase of the O'Brien CP system. These samples were returned to the Caltrans laboratory where they were immersed in a salt water solution and cathodically protected at a high current density for a duration of one year. The average current density rate applied to these laboratory specimens was approximately 99 times that provided to date to the four quadrants on the O'Brien UC (Left) bridge deck.

The results of these accelerated laboratory tests showed that even when an extreme amount of CP current was delivered to the specimens, only a small amount of corrosion occurred to the primary anode wire at one end of the test specimens where the polymer mix had not been adequately compacted by hand during sample preparation. Based on these results, no corrosion would be expected on the black iron primary anode wires, placed within the conductive polymer overlay, from the level of CP presently being delivered to the bridge deck from this system, 2.48 to 5.17 mA/m^2 (0.23 to 0.48 mA/ft^2).

8.3 Cathodic Protection Operation And Effectiveness

Throughout the 6 year study period, the preset driving voltage of each CP system remained as initially set since each system continued to achieve the required 100 mV polarization decay. The recorded driving voltages, however, varied during the study period due to natural electrical resistance changes within the CP systems.

weight polyethylene) cable on one end and plugged on the other end, as manufactured by Durichlor-51 Anode Company, P.O. Box 1363, Dayton, Ohio 45401.

Arrangements have been made to ensure that any successful bidder can obtain the Durichlor-51 Bridge Deck Anode complete with 22.9 m (75 ft) of specified cables from the source listed.

Prior to placing overlay, the Contractor shall provide access to the Engineer to conduct electrical continuity testing in the Durichlor-51 bridge deck anode system.

10.2 Metallized Zinc CP System Specifications

METALLIZING CONCRETE. This work shall consist of preparing bridge deck, metallizing concrete, electrical connectors, and asphalt concrete in accordance with details shown on the plans as specified in the Caltrans Standard Specifications, these special provisions, and as directed by the Engineer.

PREPARE CONCRETE DECK SURFACE. Preparing concrete deck surface shall consist of abrasive blast cleaning concrete deck surfaces, including exposed surfaces of brass pads, to remove remaining asphalt concrete, oil, dust, laitance, and other foreign material adhering to bridge deck, as shown on the plans.

Immediately prior to placement of overlay, the entire deck area shall be further cleaned by compressed air blasting to remove loose dust and chips.

If the surface to receive the overlay becomes contaminated, as determined by the Engineer, or if the traffic is allowed over the surface, the areas shall be recleaned by abrasive blast cleaning.

All materials which are removed shall become the property of the Contractor and shall be disposed of outside the highway right of way in accordance with the provisions in Section 7-1.13, "Disposal of Material Outside the Highway Right of Way" of the Caltrans Standard Specifications.

ELECTRICAL CONNECTORS. Brass pads, 50.8 mm x 50.8 mm x 9.5 mm (2 in x 2 in x 3/8 in) thick will be State-furnished as provided for under "Materials" of these special provisions.

Portion of bridge deck shall be removed as required for brass pad installation in accordance with the details shown on the plans.

Brass pads shall be installed prior to metallizing the deck.

Epoxy adhesive (bedding) shall be electrically non-conductive and of such viscosity as to support the brass pads in place without "flow" until the epoxy hardens. Epoxy shall be "Concresive AEX 1419" as manufactured by Adhesive Engineering Co. or equal.

After abrasive blast cleaning and before metallizing the concrete surface, the Contractor shall provide access to the cleaned area for the Engineer to conduct electrical continuity testing to without discharge damage to the anode surface. It is entirely possible that maximum current output could not be achieved with this system. Also, according to the manufacturer, the Ferex 100 anode is not recommended for use with AC overlays due to chemical incompatibility. There is also doubt that the anode material would not be damaged if it came into contact with polyester overlays. Since it would seem that a PCC overlay is the only type of overlay that is compatible with the system, the use of the Raychem "Ferex 100" would not be installed on projects where dead load of a PCC overlay is a concern.

The extremely high average polarization decay value for the Metallized Zinc CP system has not been completely understood. Inconsistent values were recorded at the same half-cell ports during different instant-off surveys. Instant-off values were recorded in excess of -1.1 volts (vs. $Cu/CuSO_4$) at several half-cell ports, while, during other surveys the same half-cell ports exhibited instant-off values in the more representative range of -0.6 to -0.7 volts. The driving voltage had not been changed.

It is suspected that the half-cell ports in question have developed leaks under the surrounding non-conductive barrier seal. The water placed in the port to make electrolytic contact during the recording period may have seeped under the barrier and brought the half-cell in electrolytic contact with the metallized zinc.

During the summer of 1990, a chip seal overlay was inadvertently placed on the bridge deck of the Upper Salt Creek UC (Left) during a routine roadway maintenance operation. No obvious difficulties or changes in recorded values to date have been noticed since the chip seal was placed on this structure.

As shown in Table 8.3-A, with the exception of the Northeast Quadrant, the average current density of the Conductive Polymer CP system applied to the O'Brien UC (Left) bridge deck is lower than those of the Upper Salt Creek UC bridges. Even so, the 4 hour polarization decay exceeded 100 millivolts on the O'Brien UC (Left) systems. The lower current density may be attributed, in part, to the impermeability of the conductive polymer overlay which would reduce the migration of oxygen to the bridge deck concrete.

The rectifier for the NW Quadrant of the Conductive Polymer CP system developed a recurring problem approximately one year after start-up of the CP systems. The malfunction was consistent with that of a dirty variable resistor contact in the variac controlling the current adjustments. The contact required repeated cleaning to maintain constant CP current delivery. No permanent repairs were made at that time. As a result, the average driving voltage and 4 hour polarization decay values for this quadrant are noticeably lower than those of the other three quadrants. In April 1992, the rectifier for the NW Quadrant was removed and the rectifier supplying current to the SW Quadrant was connected to the NW Quadrant. After this change was made, the driving voltage was increased to maintain the same current density to both Quadrants.

An independent study[13] of the Metallized Zinc, Coke Breeze, and Conductive Polymer CP systems was conducted by a corrosion consultant for the Strategic Highway Research Program (SHRP) in April/May 1992. The Introduction, Conclusions, and Recommendations of this study are reprinted, in part, in Appendix 10.11 of this report.

Laws which govern this work include but are not necessarily limited to:

1. Health and Safety Code, Division 20, Chapter 6.5 (Hazardous Waste Control Act).

2. Title 22 California Administrative Code, Chapter 30 (Minimum Standards for Management of Hazardous and Extremely Hazardous Materials).

3. Title 8, California Administrative Code.

It shall be the responsibility of the Contractor to verify with the operator of a disposal site whether the material will be accepted for disposal. This material shall only be hauled by a registered hazardous waste hauler using correct manifesting procedures and vehicles displaying current certification of compliance.

Attention is directed to the provisions for "Pavement Reinforcing Fiber" in the "Asphalt Concrete Overlay Specification" of these special provisions (see Appendix 10.6 of this report).

10.3 Raychem "Ferex 100" CP System Specifications

RAYCHEM CATHODIC PROTECTION SYSTEM. This work shall consist of installing Raychem "Ferex 100" anode strand in accordance with the details shown on the plans as recommended by the manufacturer, as specified in these special provisions, and as directed by the Engineer.

Attention is directed to the provisions in the "Controlled Slump Concrete Overlay Specification" of these special provisions (See Appendix 10.7 of this report).

Prior to placing overlay, the Contractor shall provide access to the Engineer to conduct electrical continuity testing in the Raychem Cathodic Protection System.

Anode strand shall conform to the following:

a. Anode strand shall be Ferex 100 anode strand as manufactured by Raychem Corporation. Arrangements have been to ensure that any successful bidder can obtain the Ferex Anode Strand from the source below:

   Raychem Corporation
   300 Constitution Drive
   Menlo Park, California
   Phone (415) 361-3333

The price quoted by the manufacturer is $6,893.84.
The above price will be firm for all orders placed on or before November 1, 1987.

b. The Contractor shall fasten each anode strand end loop to concrete. The anode shall be fastened to the concrete a minimum of every 3.05 m (10 ft) at cleat locations and between end loops, as shown on the plans.

Metallized Zinc CP systems,[3] and the preliminary findings to date of an ongoing long term monitoring study of that same structure, indicate that the life expectancy of metallized zinc under an AC overlay is not solely related to the volume of zinc applied. Other factors, not totally understood at this time, (e.g., the possibility of moisture trapped between the AC overlay and the concrete bridge deck, and localized "hot spots" that allow accelerated corrosion of the zinc in localized areas) come into play that can accelerate the consumption of the metallized zinc. For this reason, the estimated life expectancy of the Metallized Zinc CP system has been reduced by the authors from the initially calculated estimate (of approximately 30 years) in order to present a more conservative number that considers the unknown factors.

8.5 Installation Costs

The costs associated with installing the CP systems for this study pertain to the actual contracted installation cost including contract change orders (CCO's) made during the construction period. Testing and personnel costs for gathering research data have not been included.

For the most part, all five CP systems were installed by the same contractor using the same working personnel. Exceptions were the additional personnel required to place the concrete overlay and the coke breeze/AC overlay, and the subcontractor that performed the zinc metallizing.

The resulting costs, per square meter (square foot) of CP surface area, to install each CP system is as follows:

CP SYSTEM	COST $\$/m^2$ ($\$/ft^2$)
Coke Breeze	202.90 (18.85)
Metallized Zinc	270.60 (25.14)
Eltech "Elgard 210"	225.50 (20.95)
Raychem "Ferex 100"	202.90 (18.85)
Conductive Polymer	192.03 (17.84)

These costs include total contract costs for electrical work, primary anodes, distribution anodes, and protective overlays (AC or PCC). These costs do not include traffic control, removal of PCC surfaces and AC overlays, repairing delaminated concrete, and purchasing and installing rectifiers and controller cabinets.

d. Current shall be distributed to the anodes via Elgard titanium current distributor bars.

e. Current distributor shall be attached to the anode mesh by resistance welded metallurgical bonds. There shall be at least one weld for every 75 linear millimeters (3 linear inches of distributor bar.

f. Current distributor locations shall be as recommended by the manufacturer.

g. Current distributors shall be bent to extend through cored holes as shown on the plans. Current distributors shall be covered within the hole by an insulating heat-shrinkable sleeve approved by the Engineer. Holes shall be filled with a non-conductive epoxy approved by the Engineer.

h. Insulated anode lead wires shall be AWG No. 10 stranded copper wire with THHN insulation or approved equal. Anode lead wires shall be attached to current distributors external to the concrete using spade lug connectors, and connections shall be coated with epoxy approved by the Engineer. Wires shall be of sufficient length to eliminate any field splicing, and shall be tagged to indicate their position.

10.5 Conductive Polymer CP System Specifications

CONDUCTIVE POLYESTER CONCRETE OVERLAY. The work under this section consists of preparing concrete deck surface, applying prime coat, placing wire mesh, and placing conductive and nonconductive polyester concrete overlays in accordance with the details shown on the plans and the requirements in these special provisions.

Prior to applying the prime coat and placing polyester concrete on the bridge deck, the contractor shall arrange to have the resin material supplier furnish, (1) technical service relating to the handling of resin materials and, (2) health and safety training for personnel who are to handle the polyester styrene concrete and prime coat materials.

Each shipment of polyester styrene resin and initiators shall be accompanied by a Material Safety Data Sheet (MSDS) and Certificate of Compliance as provided in Section 6-1.07, "Certificates of Compliance" of the Caltrans Standard Specifications, certifying that the material conforms to the requirements in these special provisions.

One quart of each prime coat and binder shall be sampled from each manufacturer's lot and submitted to the Transportation Laboratory a minimum of 15 working days prior to use.

PREPARE CONCRETE DECK SURFACE. Prepare concrete deck surface shall consist of cleaning portland cement concrete deck to receive polyester concrete overlay as shown on the plans and in accordance with these special provisions.

Concrete surface shall be cleaned by abrasive blasting not more than 24 hours prior to placement of the prime coat. The creation of dust which obstructs the view of the motorist, as determined by the Engineer, will not be permitted. All surface contaminants including, but not limited to

13. "Evaluation Report, Upper Salt Creek and O'Brien Bridges along I-5, Redding, California," Prepared by Corrpro Companies Inc., for Strategic Highway Research Program (SHRP C-102F, Task 2B), Washington D.C., September 1992.

14. "Evaluation Report, Upper Salt Creek Bridge on Southbound I-5, Redding, California," Prepared by Concorr Inc., for Strategic Highway Research Program (SHRP C-102F, Task F), Washington D.C., Report No. DTFH61-94-R-00054, February 1995.

15. Bennet, J. E., Bushman, J. B., Clear, K. C., Kamp, R. N., Swiat, W. J., "Cathodic Protection of Concrete Bridges: A Manual of Practice," Strategic Highway Research Program, National Research Council, Washington, D.C., Report No. SHRP-S-372, December 1993.

16. "State-of-the-Art Report on Cathodic Protection of Reinforced Concrete Bridge Elements," Strategic Highway Research Program, National Research Council, Washington, D.C., Draft Report SHRP-91-C102D, November 1991.

The graphite flake filler for prime coat shall be commercial grade, meeting the following gradation:

GRAPHITE FLAKE GRADATION

SIEVE SIZE	PERCENT PASSING
No. 30	100
No. 50	90 - 100
No. 100	70 - 92
No. 200	15 - 35

The conductive prime coat shall consist of three parts resin and two parts graphite flakes by weight.

Just prior to spreading, the conductive prime coat shall be thoroughly mixed to ensure suspension of the graphite flakes. The first batch of promoted resin shall be limited to no more than five gallons. Larger batches may then be used if approved by the Engineer. Any significant increase in viscosity prior to placement shall be cause for rejection.

The conductive prime coat shall be uniformly applied in a manner to effect complete coverage of the surface to receive the conductive polyester concrete. The rate of spread shall be approximately 0.81 L/m^2 (1 gal/50 ft^2) of surface. The exact rate will be determined by the Engineer. The conductive prime coat shall be left undisturbed until cured to a tack-free state as determined by the Engineer. If the conductive prime coat resin becomes contaminated before concrete placement, the prime coat shall be removed by blast cleaning and fresh prime coat reapplied.

CONDUCTIVE POLYESTER CONCRETE. Conductive polyester concrete shall contain a polyester resin, graded concrete mineral aggregate, calcined coke breeze, and calcined fluid petroleum coke.

The resin shall be a unsaturated isophthalic polyester-styrene copolymer, wax free, meeting the following requirements:

VISCOSITY: Calif. Test 434; 75 to 200 CPS; 25°C (77 °F)., 20 RPM
SPECIFIC GRAVITY: ASTM: D-2849; 1.05 to 1.10 at 25°C (77 °F).
STABILITY: Calif. Test 434; 6 mos; dark at 25°C (77 °F).
ELONGATION: Calif. Test 434; 35% minimum
TENSILE STRENGTH: Calif. Test 434; 17237 kPa (2,500 PSI) minimum
STYRENE CONTENT: 45 to 50% by weight
SILANE COUPLER: 1.0% by weight of polyester-styrene resin
GEL TIME, BINDER: Calif. Test 434; 30-45 minutes at 25°C (77 °F); 120 ml sample

The silane coupler shall be an organosilane ester, gammamethacryloxypropyltrimethoxysilane.

Coke breeze asphalt concrete shall be placed only when the atmospheric temperature is above 10°C (50 °F).

Initial or breakdown rolling shall be done with roller weighing 3626 kg (4 tons). Two complete coverages shall be made. This shall be followed by a 10879 kg (12 ton) roller making 2 complete coverages.

Batch bins shall be cleaned of other aggregates before introducing coke breeze therein. Aggregates shall not be mixed.

The Contractor's attention is directed to the anode assemblies for cathodic protection to be placed along the deck before placing the coke breeze asphalt concrete. The coke breeze asphalt concrete shall be placed in such a manner that anode assemblies will not be damaged.

Coke Breeze asphalt concrete will be measured and paid for by the ton as coke breeze asphalt concrete.

The contract price paid per ton for coke breeze asphalt concrete shall include full compensation for furnishing all labor, materials, tools, equipment and incidentals, and for doing all work involved in constructing coke breeze asphalt concrete, complete in place, including cleaning loose or extraneous materials from bridge deck, as shown on the plans, as specified in the Caltrans Standard Specifications and these special provisions, and as directed by the Engineer.

DURICHLOR-51 BRIDGE DECK ANODE. This work shall consist of preparing bridge deck, furnishing and installing Durichlor-51 Bridge Deck Anode, coke breeze asphalt concrete and asphalt concrete overlays in accordance with the details shown on the plans as specified in the Caltrans Standard Specifications, and these special provisions, and as directed by the Engineer.

PREPARE CONCRETE DECK SURFACE. Preparing concrete deck surface shall be as specified for "Prepare Concrete Deck Surface" in the "Metallized Zinc CP System Specification" of these special provisions (see Appendix 10.2 of this report).

Portion of bridge deck shall be removed as required for bridge deck anode installation in accordance with the details shown on the plans.

Epoxy adhesive (bedding) shall be electrically non-conductive and of such viscosity as to support the cast iron anodes in place without "flow" until the epoxy hardens. Epoxy shall be "Concresive AEX 1419" as manufactured by Adhesive Engineering Co. or equal.

DURICHLOR-51 BRIDGE DECK ANODE. Durichlor-51 Bridge Deck Anode shall consist of furnishing and installing Durichlor-51 Bridge Deck Anode, in accordance with the details shown on the plans and the requirements in these special provisions.

Durichlor-51 Bridge Deck Anode shall be Type II, Pattern BS43954A, 228.6 mm (9 in) long, 152.4 mm (6 in) wide, and 28.6 mm (1-1/8 in) at its thickest and 14.3 mm (9/16 in) at its thinnest section; and assembled, by use of low resistant lead, with No. 8/7 HMWPE (high molecular

CALCINED COKE BREEZE AGGREGATE

SIEVE SIZE	% PASSING
12.7 mm (1/2")	100
9.5 mm (3/8")	98 - 100
No. 4	95 - 100
No. 8	68 - 85
No. 16	30 - 50
No. 30	2 - 22
No. 50	0 - 10
No. 100	0 - 7

The calcined fluid petroleum coke aggregate shall be spherical in shape and comply with the following limits:

CALCINED FLUID PETROLEUM COKE AGGREGATE

SIEVE SIZE	% PASSING
No. 16	100
No. 30	93 - 100
No. 50	68 - 95
No. 100	5 - 25
No. 200	0 - 5

The calcined coke aggregates shall have a minimum carbon value of 85% as per ASTM D-3178. At the time of mixing with the resin, the moisture content of the aggregates shall not exceed 0.5 of their percent absorption when tested in accordance with California Test 226.

The aggregate blend for the conductive polyester concrete shall be of the following composition:

60% Mineral Aggregate
30% Calcined Coke Breeze Aggregate
10% Calcined Fluid Petroleum Coke

Resin content shall be approximately 21 percent by weight of the dry aggregate. The exact resin percentage shall be determined by the Engineer, based on the materials submitted by the Contractor. The Contractor shall furnish to the Engineer, at least 15 working days prior to placement, an amount of material sufficient to produce a minimum of 0.071 m^3 (2-1/2 ft^3) concrete. The Engineer will test the materials and determine the yield to be used for determining pay quantities. The conductive polyester concrete shall have a minimum slump of 76 mm (3 in) by ASTM C-39 and shall have a maximum resistivity of 8 ohm-cm using the Wenner four-pin method on a 76 mm x 76 mm x 305 mm (3 in x 3 in x 12 in) sample. Resistance shall be measured with a Nilsson 400 soil resistivity meter after the sample has cured 48 hours at room temperature.

locate discontinuities in the electrical insulating characteristics of the concrete cover over the deck reinforcement.

If discontinuities (caused by tie wire or other metal extending too close to the concrete surface or voids in concrete) are detected, the metal shall be removed and the area patched as directed by the Engineer. Removal of metal and patching of resulting holes will be paid as extra work as provided in Section 4-1.03D "Extra Work," of the Caltrans Standard Specifications.

METALLIZING CONCRETE. Metallizing concrete shall consist of applying zinc with wire fed type conventional thermal spray equipment.

Zinc wire shall be 99.9 percent pure. The contractor shall furnish a signed certification by the manufacturer of the purity of the zinc wire and a list of impurities with quantity of each.

The concrete surface shall be dry and dust free when the zinc is applied.

Zinc shall be applied to the concrete at a uniform rate. The quantity of zinc to be sprayed shall be 3.66 kg/m^2 (75 $lb/100\ ft^2$) of bridge deck surface area.

Metallizing concrete shall be applied in uniform continuous 152 mm (6 in) wide stripes spaced at 305 mm (12 in) on centers on the transverse direction and a total of four 152 mm (6 in) wide, uniform, continuous metallizing stripes on the longitudinal direction with a stripe traversing a row of brass pads as shown on the plans.

Metallizing shall be stopped when wind or other atmospheric conditions prevent the collection of waste as specified herein or adversely affect the metallizing process as determined by the Engineer.

Good housekeeping shall be practiced during metallizing operations. Waste products and dust shall not be blown off. Precautions in the metallizing operations shall be in accordance with all applicable occupational safety and health standards, rules, regulations, and orders established by the State of California. Workmen shall use personal protective equipment including respirators and appropriate clothing. Respirators shall conform to ANSI Standard: Z 88.2.

All reasonable precautions shall be exercised to prevent the discharge of any hazardous waste material onto the ground. Hazardous waste material shall consist of residue from the metallizing process. Curtains, drapes, or other methods, approved in advance by the Engineer, shall be used to contain hazardous waste material.

No "on ground" temporary storage of hazardous waste material will be permitted.

Hazardous waste material shall be stored in leak proof bins and shall be handled in such a manner that no spillage will occur.

Disposing of hazardous waste material shall be performed in accordance with all applicable federal, state and local laws.

NONCONDUCTIVE PRIME COAT. Prior to placing the nonconductive polyester concrete electrical insulating barrier strips, a prime coat shall be applied and left undisturbed until polymerized to a tack-free state. The prime coat shall meet the requirements for the "Conductive Prime Coat" resin of these special provisions, except prime coat shall not contain conductive fillers.

The prime coat shall be uniformly applied in a manner as to completely cover the surface that is to receive the nonconductive polyester concrete. The rate of application shall be approximately 0.51 kg/m^2 (1 gal/80 ft^2) of surface. The exact rate will be determined by the Engineer. The prime coat shall be left undisturbed until cured to a tack-free state as determined by the Engineer. If the prime coat becomes contaminated before concrete placement, the prime coat shall be removed by blast cleaning and fresh prime coat shall be applied.

NONCONDUCTIVE POLYESTER CONCRETE. Nonconductive polyester concrete shall contain a polyester resin and a graded concrete mineral aggregate without conductive fillers.

The polyester resin shall conform to the requirements specified for "Conductive Polyester Concrete" in these special provisions.

The graded concrete aggregate shall conform to the requirements for concrete mineral aggregate for "Conductive Polyester Concrete" in these special provisions except aggregates shall not contain coke breeze filler.

Resin content shall be approximately 12 percent by weight of the dry aggregate. The exact resin percentage shall be determined by the Engineer, based on the materials submitted by the Contractor. The Engineer will test the materials and determine the yield to be used for determining pay quantities.

The nonconductive polyester concrete shall be mixed without conductive fillers. Placing nonconductive polyester concrete shall conform to provisions for placing conductive polyester concrete in these special provisions.

FINISHING. Conductive and nonconductive polyester concrete overlays shall be consolidated to a relative compaction of not less than 97 percent, as determined by the Engineer. Copies of the test procedure, "Method of Test for Determining the Compaction of Polymer Concrete," are available at the Transportation Laboratory, 5900 Folsom Blvd. (P.O. Box 19128), Sacramento, CA 95819.

Finishing equipment shall be capable of striking off the concrete to the grade established by the Engineer in such a manner as to achieve enough compaction to cause resin to flush to the surface. Finishing equipment used for the conductive polyester concrete shall be self-propelled and shall be sufficiently heavy to ensure that the finished surface will be at the grade established by the Engineer. Shuttling, vibrating, spinning, or combination thereof shall be used to provide satisfactory results. Drawings for all equipment used for strike-off and consolidation shall be submitted by the Contractor for review 15 days before use. Such drawing shall show the working parts of the equipment.

c. The Contractor shall install additional cleats and fasteners as directed by the Engineer to ensure that the anode strand lies flat during placing of concrete overlay.

d. The Contractor shall take precautionary measures to prevent any damage to the anode strands during anode installation and concrete overlay placement. Damaged anode strands shall be repaired or replaced by the contractor at his expense. All repair or replacement shall be in accordance with the manufacturer's recommendations.

e. All cleats, fasteners, wires and splices shall conform to the anode manufacturer's requirements.

10.4 Eltech "Elgard 210" CP System Specifications

ELTECH CATHODIC PROTECTION SYSTEM. This work shall consist of installing Eltech "Elgard 210" anode mesh in accordance with the details shown on the plans, as recommended by the manufacturer, as specified in these special provisions, and as directed by the Engineer.

Attention is directed to the provisions in the "Controlled Slump Concrete Overlay Specification" in these special provisions (see Appendix 10.7 of this report).

Prior to placing overlay, the Contractor shall provide access to the Engineer to conduct electrical continuity testing in the Eltech Cathodic Protection System.

Anode mesh shall conform to the following:

a. All anode material shall be ELGARD expanded titanium mesh anode as manufactured by Eltech Systems Corporation.

Arrangements have been made to ensure that any successful bidder can obtain the Elgard Anode Mesh from the source listed below:

ELTECH Systems Corporation
625 East Street
Fairport Harbor, Ohio 44077
Phone (216) 357-400

The price quoted by the manufacturer is $8,950.
The above price will be firm for all orders placed on or before October 27, 1987.

b. Anodes shall be placed as shown on the plans.

c. Anodes shall be fastened to deck with insulating fasteners recommended by the manufacturer and approved by the Engineer, to not more than 12.7 mm (1/2 in) from surface of the deck. At least one fastener shall be used for every 0.46 m^2 (5 ft^2) of deck surface.

10.6 Asphalt Concrete Overlay Specifications

ASPHALT CONCRETE (BRIDGE). Asphalt concrete shall be Type B and shall conform to the provisions in Section 39, "Asphalt Concrete" of the Caltrans Standard Specifications and these special provisions.

Attention is directed to the provisions in "Pavement Reinforcing Fiber" of these special provisions for asphalt concrete to be placed over bridge deck.

The aggregate for use in the asphalt concrete shall conform to the provisions in Section 39-2.02, "Aggregate," of the Caltrans Standard Specifications, and the following:

The grading of the aggregate shall be 12.7 mm (1/2 in) maximum, medium.

The grading of the aggregate in sections or tapers at bridge ends, less than 25 mm (1 in) in total depth, may be No. 4 maximum. Material passing the No. 8 sieve shall contain no crushed particles.

The asphalt binder shall be Grade AR 4000.

The amount of asphalt binder to be mixed with the aggregate shall be between 5 percent and 8 percent by weight of the dry aggregate as determined by the Engineer.

Paint binder shall be RS-1 or CRS-1 grade asphalt emulsion.

The asphalt concrete for the first layer shall be spread at such temperature that all initial or breakdown rolling is performed when the temperature of the mixture is between 110 and 138°C (230 and 280°F).

Asphalt concrete shall be placed only when the deck surface temperature is above 10°C (50°F).

The reduction in weight of roller provided for in Section 39-6.03, "Compacting," of the Caltrans Standard Specifications, shall not apply.

Placing of asphalt concrete for the first layer on bridge decks with grade over 2 percent shall be done in a downhill direction.

Spreading equipment need not be self propelled.

At no time shall the difference in grade between adjacent lanes that are open to public traffic exceed 0.05 m (0.15 ft).

PAVEMENT REINFORCING FIBER. Polyester reinforcing fibers shall be added to the asphalt concrete for asphalt concrete overlay on bridge decks as shown on the plans and as specified in these special provisions.

rust, oil, paint, curing compound, joint materials, asphalt concrete, and other foreign materials shall be removed from the surface of existing concrete.

Water may be used to aid in the cleaning prior to abrasive blasting, but the surface of the concrete shall be visibly dry for minimum of 24 hours immediately prior to placing the prime coat.

All paving equipment shall be fitted with suitable traps, filters, drip pans, or other devices to prevent oil, fuel, grease or other deleterious matter from being deposited on the cleaned portland cement concrete surface, on prime coat, or overlay.

Any area that becomes contaminated shall be recleaned at the Contractor's expense. Any conductive paths that could cause a short circuit between the conductive overlay and the steel to be protected shall be adequately insulated. Such short circuits shall be eliminated by means approved by the Engineer at the Contractor's expense.

Immediately prior to placing the prime coat, the surface shall be cleaned by compressed air to remove dust and any other loose material.

Prior to placing prime coats, the surface temperature of the area to receive the prime coat shall be between 4 and 38°C (40 and 100 °F), and the surface shall be visually dry. Methods proposed to heat said surfaces are subject to approval by the Engineer.

CONDUCTIVE PRIME COAT. Prior to placing the conductive polyester overlay, a conductive prime coat shall be applied. The prime coat shall be a composite of polyester resin containing graphite flakes. Prime coat resin shall be 100 percent reactive wax-free unsaturated diaromatic oxide glycol fumarate modified polyester resin with the following unfilled resin characteristics:

**** (NOTE - the originally specified resin was incorrectly specified and the following material was correctly under a contract change order) ****

VISCOSITY: ASTM: D-2393; 150-300 CPS, 25°C (77 °F), 20 RPM #1 spindle
SPECIFIC GRAVITY: ASTM: D-2849; 1.00-1.02 AT 25°C (77 °F).
STABILITY : 6 mos.; dark at 25°C (77 °F)
GEL TIME : Calif. Test 434; 25-30 minutes (120 ml Sample)
ELONGATION: ASTM: D-638; 1-6%
TENSILE STRENGTH: ASTM: D-638; 31026 kPa (4500 psi) minimum
STYRENE CONTENT : (Volatiles) 40-55% by Weight
BARCOL HARDNESS: ASTM: D-2583; 30 to 40 at 25°C (77 °F).

The silane coupler shall be an organosilane ester, gammamethacryloxypropyltrimethoxysilane.

Prime coat resin shall be initiated using methyl ethyl ketone peroxide and/or cumene hydroperoxide initiators to provide the desired gel times. The peroxide initiator percentage shall be adjusted in the field to provide a prime coat gel time between 1/2 to 4 hours.

Immediately prior to placement of concrete overlay, the entire deck area shall be further cleaned by compressed air blasting to remove loose dust and chips.

If the surface to receive the concrete overlay becomes contaminated, as determined by the Engineer, the areas shall be recleaned as provided above.

All materials which are removed shall become property of the Contractor and shall be disposed of outside the highway right of way in accordance with the provisions in Section 7-1.13, "Disposal of Material Outside the Highway Right of Way" of the Caltrans Standard Specifications.

Controlled slump concrete overlay shall conform to the requirements in Section 51, "Concrete Structures" of the Caltrans Standard Specifications and these special provisions.

MATERIALS. Portland cement shall be Type II modified conforming to Section 90-2.01, "Portland Cement" of the Caltrans' Standard Specifications. The use of pozzolan or Type IP (MS) modified cement will not be permitted unless aggregate is found to be deleterious or potentially deleterious.

**** (NOTE: This specification was changed during construction to add a single mat of #3 epoxy coated reinforcing steel to be placed at mid depth in the concrete overlay -- see description in Section 5.5 of this report). ****

The concrete for the controlled slump concrete overlay shall contain a minimum of 390 kilograms of portland cement per cubic meter (658 pounds of portland cement per cubic yard).

Aggregate for controlled slump concrete overlay shall contain between 50 and 55 percent fine aggregate.

Grading of fine aggregate shall conform to the provisions in Section 90-3.03, "Fine Aggregate Grading," of the Caltrans Standard Specifications. Grading of coarse aggregate shall conform to the following:

AGGREGATE GRADATION

SIEVE SIZE	PERCENT PASSING
19.1 mm (3/4")	100
12.7 mm (1/2")	90 - 100
9.5 mm (3/8")	40 - 70
No. 4	0 - 15
No. 8	0 - 5

A water reducing admixture conforming to ASTM Designation C-494 Type A or F shall be used.

Dosage rate of the chemical admixture shall be as per manufacturers' recommendations to achieve a workable mix.

Admixture approved shall conform to Section 90-4.03, "Admixture Approval," of the Caltrans Standard Specifications.

The thickness of the overlay shown on the plans is the minimum to be placed and may be increased to provide a smooth finished grade, but shall not exceed 88.9 mm (3-1/2 in).

Placing controlled slump concrete overlay shall be in accordance with the details shown on the plans, the requirements in Section 51, "Concrete Structures," of the Caltrans Standard Specifications and these special provisions.

The finished surface of the controlled slump concrete overlay shall conform to the requirements in Section 51-1.17, "Finishing Bridge Decks," of the Caltrans Standard Specifications.

The thirteenth paragraph in Section 51-1.17, "Finishing Bridge Decks," of the Caltrans Standard Specifications shall not apply.

TEXTURING BRIDGE DECK SURFACES. Except as provided for in paragraph ten of Section 51-1.17, "Finishing Bridge Decks," of the Caltrans Standard Specifications, all concrete bridge deck surfaces shall be textured.

The texture shall be indentations 4.76 ± 1.59 mm (3/16 ± 1/16 in) in depth. The indentations shall be approximately 3.2 mm (1/8 in) in width spaced approximately 19.1 mm (3/4 in) on centers. Overlaps of the texturing shall be avoided. Indentations or corrugations shall be transverse to the roadway centerlines and cover the full deck to a neat line 305 mm (12 in) from face of rail or curb.

At the Contractor's option, the bridge deck surfaces may be textured by use of grooving machine in accordance with the provisions in Section 42, "Grooving and Grind Pavement," of the Caltrans Standard Specifications.

10.8 Half-Cell Access Ports Installation Procedure

The installation technique of all half-cell ports used in this study conformed to the following:

HALF-CELL ACCESS PORTS. Holes 114.3 mm (4-1/2 in) in diameter were cored or formed through bridge deck overlays to expose the original bridge deck surfaces.

The concrete deck surface exposed within the holes was thoroughly cleaned of all conductive materials and coatings using a pneumatic chipping hammer.

After cleaning, the holes were backfilled with a nonconductive mix of polyester resin. Sand (approximately #8 sieve size) was added to the resin as a filler to minimize the effects of shrinkage. All surfaces within each 114.3 mm (4-1/2 in) diameter cored hole was thoroughly wetted with the resin/sand mix during placement to ensure bonding.

The mix ratio is as follows:

Polyester Resin...........473 ml (16 fl. ounces)
Catalyst......................4.9 ml (1/6 fl. ounce)
#8 Sand......................3.2 kg (7 lbs)

The polyester resin used conformed to the specifications of that called for in the Conductive Polyester Concrete mix described in Appendix 10.5.

Following the curing of the resin/sand mix, 31.75 mm (1-1/4 in) diameter holes were cored through the center of each resin/sand filled hole to expose the original bridge deck surface. The exposed bridge deck surface was cleaned using a hammer and chisel to remove all resin residue. This resulting hole is used to place the half-cells during monitoring tests.

While all half-cell ports were constructed generally the same, each had a somewhat different cross-section due to the differences of each type of CP system. Figure 10.8-A shows these details.

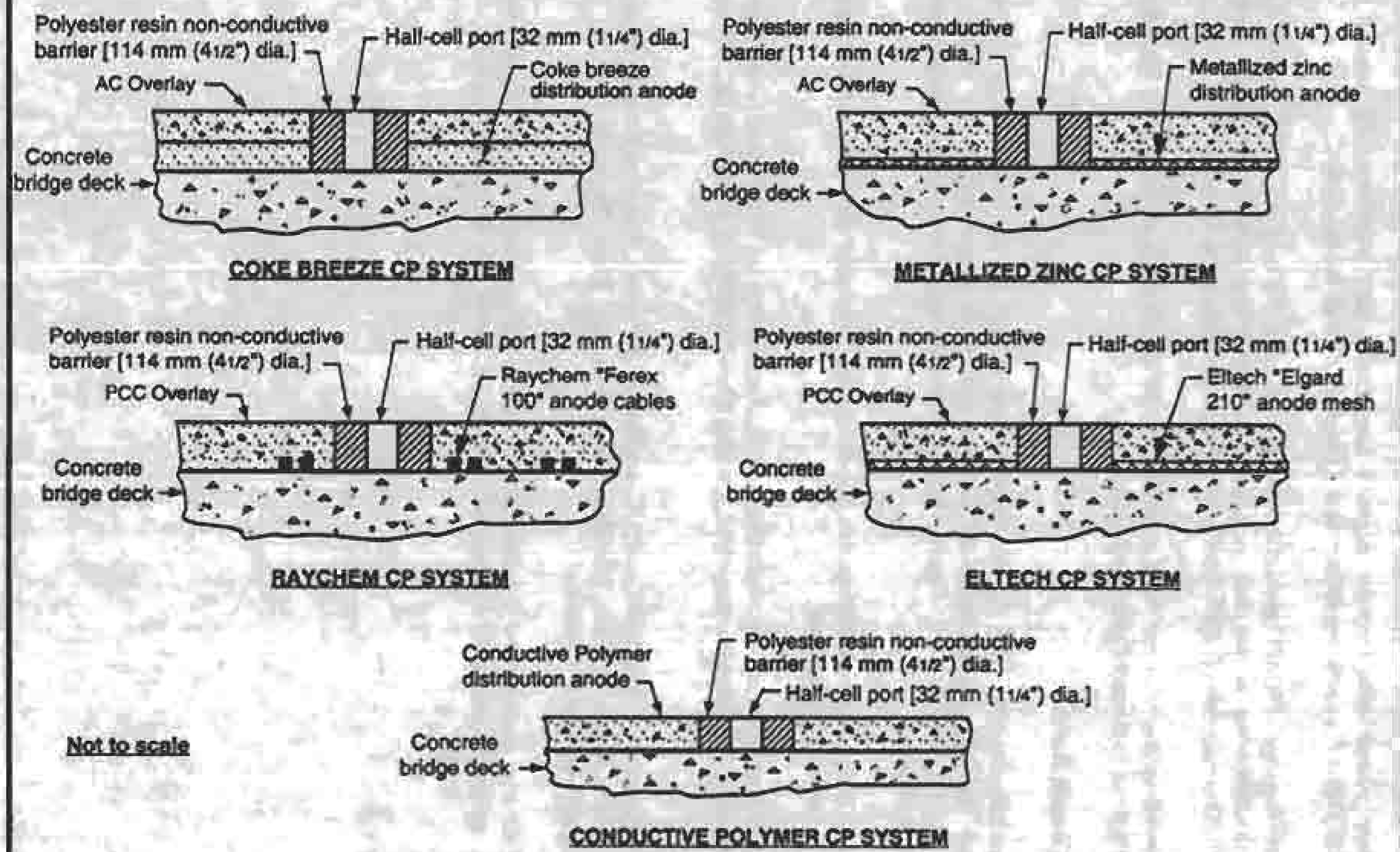


FIGURE 10.8-A Typical Cross Section of Half-Cell Ports

10.9 Rebar Electrical Ground Connections

The rebar ground leads (rectifier negative connectors) were exothermically welded by the CADWELD process to the top rebar mat at 2 locations of each bridge deck.

Stranded #8 gauge HWMPE insulated wires were used at the CADWELDED locations and to extend through holes in the deck to a conduit collector system under the bridge deck. All CADWELD connections and adjacent rebar surfaces were potted with epoxy.

Both wires from the rebar mat were connected to a single #8 gauge stranded PVC insulated wire for the final run to the rectifier control boxes.

10.10 Control Boxes

All electrical circuitry, with the exception of that needed for the placement and wiring of temporary half-cells during instant-off surveys, was wired permanently to the control boxes located under the structures. Figure 10.10-A shows a typical control box installation with rectifiers in place.

The control boxes and rectifiers used in this study were the same ones used in the original CP installation at these bridge sites[2].

The control boxes (one at Upper Salt Creek UC and one at O'Brien UC) housed 6 rectifiers each. The rectifiers are a constant voltage type, Goodall Model CPAWSA 10/20 volt DC, 5/3 ampere, GZ.

Each rectifier, at the Upper Salt Creek UC installation, provides CP current for each of the 6 CP systems (Coke Breeze/Asphalt, Metallized Zinc, Raychem Deck, Raychem Overlay, Elgard Deck, Elgard Overlay CP Systems).

Each of the four quadrants of the Conductive Polymer CP system at O'Brien UC are supplied cathodic protection current by a separate rectifier in the control box under that structure.

FIGURE 10.10-A Typical Control Box Installation with Rectifiers

10.11 Evaluation Report, Strategic Highway Research Program C-102F, Task 2B.

The following are the Introduction, Conclusions and Recommendations as reported by the Strategic Highway Research Program based on tests conducted on the Metallized Zinc, Coke Breeze, and the Conductive Polymer CP systems.[13]

INTRODUCTION: On April 26 through May 1, 1992, the Strategic Highway Research Program (SHRP) contractor performed a cathodic protection system evaluation on select bridges along I-5 in Redding, California. This project is part of an overall effort for which the contractor was retained by SHRP under Contract C-102F Task 2B, to develop a performance assessment and guideline for the existing cathodic protection systems and their related components in the United States and Canada. This information gathered by SHRP C-102F will provide the State Highway Agencies (SHA's) with additional state-of-the-art information for evaluating and maintaining the existing cathodic protection systems and designing new cathodic protection installations.

A primary objective of this project is to investigate, document field operating data, and evaluate the performance of existing cathodic protection systems. The type of systems evaluated during this study and their locations are as follows:

1. Metallized Zinc CP system: Upper Salt Creek Bridge #6-159L, South End.
2. Coke Breeze CP system: Upper Salt Creek Bridge #6-159L, North End.
3. Conductive Polymer CP system: O'Brien Bridge #6-148L.

The cathodic protection system investigation and evaluation performed on the above mentioned systems and bridges includes the following:

1. Visual inspection.
2. Rectifier output verification testing.
3. Electrical resistance measurements.
4. Polarization decay testing.
5. E Log I testing.
6. Historical data review.

RESULTS: The contractor obtained the following results for the 4-hour polarization decay:

SYSTEM	HALF-CELL PORT	POLARIZATION DECAY (mV)
Metallized Zinc	4A	363
	4C	525
	4E	286
Coke Breeze	4G	149
	4I	150
	4K	233
	4L	255
Conductive Polymer	4A	291
	4E	247
	4I	254
	4L	277

CONCLUSIONS: Based on the results and analysis of this evaluation, the following conclusions are made:

1. Based on the NACE 100 mV potential decay criterion and visual inspection, the reinforcing steel is are receiving effective corrosion control on all three systems.

2. The E Log I tests results indicate higher current requirements than that needed to satisfy the 100 mV decay criterion.

3. Initially a fixed current density, 10.8 mA/m^2 (1 mA/ft^2) of concrete surface, resulted in polarization decay values which greatly exceeded the NACE 100 mV polarization decay criterion after a short period of time.

4. All systems have been powered for the last 4 years by voltage control rectifier circuits that were initially adjusted to provide 8.39 mA/m^2 (0.78 mA/ft^2), top mat steel surface, to the zinc stripe and 5.81 mA/m^2 (0.54 mA/ft^2) conductive asphalt systems and 3.2 mA/m^2 (0.3 mA/ft^2) for the conductive polymer styrene system.

5. The rectifier is voltage adjustable but does not control at a fixed constant voltage output. The voltage output range is dependent on the anode to structure circuit load resistance. The following table summarizes the 4 years of monitoring data:

ANODE SYSTEM	RECTIFIER VOLTAGE RANGE (Volts)	RECTIFIER CURRENT RANGE (mA)	ANODE TO STRUCTURE CIRCUIT RESISTANCE (Ohms)
Zinc Stripe	1.10 - 1.88	300 - 1100	0.70 - 6.27
Conductive Asphalt	1.91 - 2.87	400 - 1200	1.75 - 22.3
Conductive Polymer Styrene South Zone	1.20 - 2.20	40 - 900	1.66 - 53.75
Conductive Polymer Styrene North Zone	1.82 - 3.62	80 - 1400	2.17 - 42.75

6. Unlike the typical cathodic protection system, the conductive polymer styrene system averaged higher current output in the warmer months as shown below:

ANODE SYSTEM	AVERAGE CURRENT OUTPUT (mA)	
	April - September	October - March
Zinc Stripe	541	439
Conducive Asphalt	650	532
Conductive Polymer Styrene, South Zone	294	220
Conductive Polymer Styrene, North Zone	158	294

7. Anode to concrete disbondment was found on the conductive polymer styrene system.

8. Rust stains and cracks along the anode connector wire were evident on the conductive polymer styrene system. This cracking appears to derive from corrosion of the steel wire.

9. "Instant-off" potential values are dependent on the test equipment averaging cycle and the time increment to obtain the first measurement. Significant differences can occur within the first 1/2 second the system is turned off.

10. CALTRANS bases their steel surface area on top mat steel only for the bridge deck cathodic protection analysis.

11. All systems are being very adequately monitored.

RECOMMENDATIONS: Based on the conclusions from this evaluation, the following recommendations are made:

1. Perform polarization decay testing at the lowest current output (highest circuit resistance) to determine if the NACE 100 mV decay criterion is achieved.

2. Research the "instant-off" potential measurement by using an oscilloscope and recording the exact curve the instant the rectifier power is disconnected from the anode-to-structure circuit. The "instant-off" measurement will be the potential value where the normal decay curve starts.

3. Consider the use of low corrosion rate anode materials (i.e. platinized or mixed metal oxide coated titanium wire) for the anode connector for the conductive polymer styrene system.

4. Continue the routine monitoring program to assure system long term effectiveness.

10.12 Evaluation Report, Strategic Highway Research Program C-102F, Task F

The following are the Introduction, Conclusions, and Recommendations as reported by Concorr, Inc., consultant hired by the Strategic Highway Research Program (SHRP), based on tests conducted by the SHRP consultant on the Metallized Zinc and the Coke Breeze/Conductive Asphalt CP Systems, conducted from October 31 to November 4, 1994.[14] Those portions of the report are reproduced as follows:

INTRODUCTION: The Federal Highway Administration is conducting a research program entitled "Concrete Bridge Rehabilitation and Protection." This program is a continuation of a portion of the research conducted under the Structures Program of the Strategic Highway Research Program (SHRP). The primary objective of this effort is to determine the effectiveness of cathodic protection, electrochemical chloride removal and inhibitors admixed with patching material. This is to be achieved through long term evaluation of approximately 30-42 test sites in the United States and one Canadian Province. The secondary objective of this research is to identify the most appropriate laboratory and field test method(s) for evaluating and monitoring the performance of the corrosion control techniques and procedures involved in the project.

Task F of this program requires monitoring the long term performance of existing cathodic protection installations that were previously evaluated under a Strategic Highway Research Contract (SHRP C-102F). As part of this Task, CONCORR, Inc. performed evaluations of two different cathodic protection systems installed on South bound Upper Salt Creek Bridge on Interstate-5 in Redding, California. These systems have been developed by the California Department of Transportation. The two cathodic protection systems along with their respective locations are listed below.

Bridge Location	Description of System
Upper Salt Creek Undercrossing, Bridge #6-159 L, Southbound (north end)	Coke Breeze, Conductive Asphalt
Upper Salt Creek Undercrossing, Bridge #6-159 L, Southbound (south end)	Metallized Zinc, Conductive Asphalt

The following work was conducted during the evaluation of the cathodic protection systems:

1. Review of design drawings and past reports.
2. Visual inspection and photographic demonstration.
3. Evaluation of the rectifier and other cathodic protection system components.
4. Polarization development and decay testing.
5. Sampling for and analyses of the total chloride ion content.

Two additional days were required for the evaluations due to circumstances beyond our control. Breakdown of the rectifier circuit breaker on the first day and inclement weather on the second day were the causes of the delay.

RESULTS: The contractor obtained the following results for the 4-hour polarization decay:

SYSTEM	HALF-CELL PORT	POLARIZATION DECAY (mV)
Metallized Zinc	1A	Invalid
	1B	Invalid
	1D	Invalid
	1F	Invalid
	4A	Invalid
	4C	Invalid
	4E	Invalid
Coke Breeze	1H	681
	1J	485
	1L	463
	4G	157
	4I	214
	4K	266
	4L	355

CONCLUSIONS:

1. The overall condition of the bridge deck is good.

2. No signs of ongoing corrosion were observed on rebars exposed during core sampling.

3. All CP system components of both systems are functioning properly.

4. The voltage and current meters installed on the rectifier are not functioning properly.

5. The steel polarization in Zone 2 (ed. note; Coke Breeze CP system) is significantly higher than the 100 mV criterion specified in NACE Standard RP0290-90.

6. The potential wells in Zone 1 (ed. note; Metallized Zinc CP system) are not functional. Therefore, valid data for polarization development and decay testing could not be obtained.

7. The cathodic protection current output varies with ambient temperature since the rectifier is operated in the constant voltage mode.

8. At the location sampled in Zone 1, the chloride content at the rebar depth is below the threshold required to initiate corrosion. Tests results at one location in Zone 2 indicated that the chloride content at a depth up to 38.1 mm (1.5 in) slightly exceeds the threshold level.

9. Although it is cumbersome to use, the polarization decay test equipment and software developed by CALTRANS is considered to be good.

RECOMMENDATIONS:

1. Install new potential wells in Zone 1 to allow accurate measurement of polarization development and decay.

2. Check system operation quarterly and collect rectifier data during each visit to ensure proper functioning of the CP system until the next detailed evaluation. Alternatively, install a remote monitoring unit to allow regular monitoring.

3. The technique for estimating instant-off potentials from data collected by the CALTRANS equipment and software should be modified. The data obtained should be plotted (measured potential versus elapsed time) and the first or second potential reading after the current in the cathodic protection system has decreased to zero should be used as the instant-off potential.